SUSTAINABLE WATERWAY TRANSPORT, CLEAN AIR

B.4 Modelling, evaluating and scenario building

Harbour monitoring Part C:

Emission inventories of the Neuss and Duisburg port areas

CLEAN INLAND SHIPPING

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* Calculation of emissions at the Duisburg locks with **LuWas**

B.4 Modelling, evaluating and scenario building

Harbour Monitoring Part C:

Emission inventories of the Neuss and Duisburg port areas

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1. Introduction

Despite steady improvement in air quality in North Rhine-Westphalia in recent years, compliance with the binding limit values of the EU Air Quality Directive (1) remains a challenge, especially in urban agglomerations, which requires the definition of effective measures to improve air quality in the short term as part of clean air plans. In addition to road traffic, which is usually the main source of air pollution in city centres, the emissions from inland waterway vessels also represent an important source of air pollution for municipalities along waterways.

The objective of this report is to document the emissions used by the LANUV as a basis for the evaluations (root cause analysis) of the results of the CLINSH special measurement programme. Based on the evaluation of the current CLINSH results, a contribution is to be made to further develop the currently possible description of inland vessel emissions and their effects on air quality on the basis of the evaluation of current vessel data.

To improve the data situation of emissions caused by inland vessels, in 2018 the LANUV carried out a measurement campaign in the port areas of Duisburg and Neuss/Düsseldorf with NO_2 passive collectors as part of a CLINSH special measurement programme. In addition, in both study areas an automatic measuring station monitored the parameters NO and NO_2 along with meteorological data and particle concentration in five-minute intervals.

In order to be able to quantify the share of NO_X immissions caused by shipping traffic at the individual measuring points, the shares of the various pollution sources (ship emissions, emissions from road and rail traffic, industry, background pollution, etc.) shall be determined using a dispersion model (cause analysis). These calculations require the emission quantities of the individual pollutant sources in the Duisburg and Neuss/Düsseldorf port areas as well as data on the characteristics of these sources.

The required emissions from road, rail and shipping traffic for the year 2018 were determined in detail for both port areas as part of the CLINSH project. Such data was previously not available or not available in the necessary resolution.

The study included the preparation of emissions for an extended study area, which covered both port areas. Emissions from the surrounding area, such as air traffic, industry and from small combustion plants and road traffic, were also taken into account. Depending on the emitter group, the emissions are included in the modelling as point, line or area sources. For industrial plants, the emission level (point source stack) was also taken into account. The data basis for these emissions were the emission cadastres kept by the LANUV and the data collected specifically for the urban areas of Neuss, Düsseldorf and Duisburg as part of the preparation of the air quality plans.

This part of the report covers the basics and results of the emission determination for the port areas of Duisburg and Neuss and the inland waterway traffic in these port areas. Furthermore, this report shows the combined emissions of the other emitter groups, which serve as input data for the immission (air quality) modelling of the LANUV NRW for the CLINSH project to determine the shares of the individual emission sources.

2. Basic information on the emission inventories

2.1 Existing emission data

The Environmental Agency of North Rhine-Westphalia (LANUV NRW) maintains the statewide emission cadasters and provides the technical basis for the implementation of the EU Air Quality Directive [(1)] and the air quality plans to be drawn up in the municipalities where limit values are exceeded. For this reason, many of the emission data also required for the modelling in the CLINSH project are already available for the Duisburg and Neuss/Düsseldorf study areas in the latest version and can also be used for CLINSH. These data are shown in Chapter 5.

2.2 Additional emission data collected for CLINSH

In addition to the emission data already available for the air quality plans, the modeling of the shares of the individual emitter groups in the immission load in the port areas of Duisburg and Neuss/Düsseldorf required additional data.

These included detailed information on road traffic in the port areas, traffic on the port's own railroads and off-road traffic with the forklifts used primarily for container transport.

These data were additionally collected especially for the CLINSH project. We would like to thank the port operator **Rheincargo** (Neuss port area) and the **City of Duisburg** (Duisburg port area) for carrying out the additional traffic counts in the port area. The data collection on the operation of the port railways and on the industrial trucks was also carried out with the support of the port operators.

2.3 New methodology for recording NO_X emissions from moving inland vessels

The previous emission cadastre of the state of North Rhine-Westphalia for inland waterway vessel emissions is based on ships' data in traffic reports of the WSV (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, Federal Waterways and Shipping Administration), as far as these were available. In addition, various assumptions and estimates on ship traffic have so far been made, because detailed official data was not available. Furthermore, assumptions had to be made up to now about the average motorization of ships and average ships' speeds, on the basis of which the emissions were determined using derivations from generalised power/emission curves for ship engines.

In the scope of the CLINSH project, LANUV NRW and the University of Bremen, managed to directly record the NO_X emissions of passing inland vessels by onshore measurements and derive onshore emission factors from the individual ship peaks. We classified more than 18,000 individual factors (16,000 for shipping on the Rhine and 2,000 for port traffic) according to ship size, direction of travel (upstream/downstream) and travel speed. We also carried out a detailed analysis of shipping traffic and speeds of the different vessel classes, which has already been published as a CLINSH report and LANUV technical report [(2a)].

Together with the recording of real ship traffic based on AIS (Automatic Identification System) signals, we were able to develop a new method for the calculation of inland ship emissions from the combination of both data sets and to use it for the study areas in Neuss/Düsseldorf and Duisburg within the scope of the CLINSH project. The state of NRW plans to update its own emission cadastre on this basis and to refine the method. The method development and the application for the emission surveys in CLINSH are described in detail in the joint CLINSH report of the LANUV and the University of Bremen "*Harbour monitoring Part E: Determination of NO_X emission rates of passing vessels from onshore measurements, comparison to onboard observations and application for emission calculations*" (2) and in a LANUV technical report (2a).

2.4 New methodology for the determination of emissions from horizontal ships

Since there was no applicable methodology for the realistic determination of emissions from moored ships available for CLINSH, the LANUV NRW developed an own method for this purpose. The basis for this methodology were the numbers of ships moored in the port, their average mooring times and the derivation of average emission factors per ship type. The developed method has already been used within the framework of CLINSH for the port areas of Neuss/Düsseldorf and Duisburg.

A detailed description of the method can be found in the CLINSH report of the LANUV "Harbour Monitoring Part B: Determination of NO_X and particulate matter emissions from inland vessels at berth"(2) and in a LANUV technical report (2a). A description of the application of the methodology can be found in chapter 4 of this report.

3. Emissions from moving ships on the Rhine

3.1 Input variables and description of the calculation method

The determination of emissions was carried out with the objective to represent the pollution situation as accurately as possible and to use real measured data as a data basis. For the previous inland vessel cadastre in NRW, no data on the actual shipping traffic on the waterways and in the ports was available for evaluation.

For some years now, inland vessels have also been obliged to continuously transmit AIS signals (Automatic Identification System, an automatic identification system to be obligatorily used by commercial vessels). With these signals, it has become possible to collect data on real vessel traffic. The AIS-Signal is an electronically transmitted identifier, which every commercially sailing ship must send at intervals of a few seconds to minutes. Among other things, it contains information about the size and type of the respective ship and its position and speed.

The AIS-signals make it possible to identify passing vessels as a tanker, cargo ship, passenger ship, coupled or pushed convoy or "other ship". The ships can also be classified according to their size, their direction of travel (upstream/downstream) and their speed. The size classification was based on the scheme of the Dutch "Buerau Voorlichting Binnenvaart" (4), which is oriented towards the CEMT (European Conference of Ministers of Transport, French: Conférence Européenne des Ministres des Transports (CEMT)).

Classes in steps of 1.0 m/s were defined for the classification of the velocities. This classification was also used as a basis for determining the emission factors. Furthermore, with this classification, it is possible to apply different emission factors for the emission calculations for each combination of direction of travel, ship speed and ship size. The emission calculation was carried out separately for each Rhine km covered by one of the AIS receivers set up for CLINSH in the automatic measuring stations.

3.2 Calculation of emissions

For the calculations of NO_X emissions from moving vessels, three different situations were

Sailing ships on the Rhine: The calculations of the emissions of the moving ships on the Rhine were carried out by means of the traffic registration via the AIS signals and by applying the emission factors determined from the measurements of the automatic measuring station on the Rhine in the port area of Duisburg **(DURH)**.

Sailing ships in the harbour basins: To calculate the emissions of ships, travelling in the harbour basins, special emission factors for harbour traffic (waters without current) were derived from the measurements of the automatic measuring station at the Neuss harbour (NERH). The whole traffic situation was recorded via the AIS signals.

Locking operations: The calculation of emissions for the approach to the two locks in Duisburg and lock operation poses a special challenge. Here, there are braking and acceleration processes upstream and downstream of the lock. During the actual lock operation of approx. 20-30 minutes, the ships' main engines run at idle. For these calculations, the updated model for determining the air pollution load on waterways (**LuWas)** of the Federal Institute of Hydrology (BfG) was used.

3.3 NO_X emissions of sailing ships on the Rhine

A detailed description of the derivation of the onshore emission factors and the application of the calculation method can be found in the joint CLINSH report by the LANUV and the University of Bremen "*Harbour monitoring part E: Determination of NO_X emission rates of passing vessels from onshore measurements, comparison to on-board observations and application for emission calculations*" [(2)].

The emissions caused by moving ships on the Rhine were calculated in sections per kilometre of the Rhine, since the number of ships moving on this section, as well as their respective speed can vary due to factors such as river morphology, current quays, port exits and traffic density.

For considerations under the EU Air Quality Directive [(1)], it is common practice to record the total amount of emissions for the respective urban area. For shipping, the river sections belonging to the urban area are usually evaluated. The urban areas of Neuss and Düsseldorf include the section of the Rhine from Rhine km 718-760, followed directly by the Duisburg urban area with the section of the Rhine from km 761-797.

The emission quantities of ships, sailing on the Rhine in the area of Neuss/Düsseldorf, determined by means of the new "onshore" method for calculating emissions, were 1,643 t NO_X in 2018 and 1,588 t NO_X in 2019 (Table 1).

For the area of Duisburg, the new method resulted in an emission quantity of shipping traffic on the Rhine of 2110 t NO_X for the year 2018. In 2019, these emissions for NO_X were 1,906 t and in 2020 1,882 t (Table 1).

Table 1: NO_X emission levels of ships sailing on the Rhine near Neuss/Düsseldorf and Duisburg in the years 2018-2020.

		Emissions of NO_X (t/a)		
Area	**Rhine-km**	**2018**	**2019**	**2020**
Neus/Düsseldorf	**718-760**	**1,643**	**1,588**	**no data**
Duisburg	**761-797**	**2,100**	**1,906**	**1,882**

Model-based calculations, for example for polluter analyses, are carried out using the respective emission densities for different river sections in the form of georeferenced line sources. These emission densities are defined as emission quantity/per length section.

Table 2 shows the annual emission quantities for different river kilometres of the Rhine.

Table 2: Emission densities of ships sailing on the Rhine at different Rhine-kilometers.

	NO_X-Emissions of inland vessels per Rhine-kilometers (t/km)		
Rhine-km	**2018**	**2019**	**2020**
730	**36.3**	**35.8**	**--**
740*	**53.3**	**49.0**	**--**
750	**47.2**	**42.9**	**--**
772	**45.5**	**42.4**	**39.6**
782**	**58.7**	**50.1**	**50.0**
792	**57.7**	**48.4**	**47.1**

***Port of Neuss (Measuring Station NERH); **Port of Duisburg (Measuring Station DURH)**

3.3.1 *Comparison of the emission quantities per annual quarter in the Duisburg section of the Rhine*

In addition to the annual evaluation of the total emissions, the available data were also examined for differences of any seasonal distribution in the NO_X emission quantities. It turned out that in the area of Duisburg in 2018 there was a tendency towards higher emissions in the last two quarters. The reason for this was the low water level of the Rhine in the second half of the year, which led to more shipping traffic, as the larger ships could no longer sail fully loaded (2a). In 2019, the data showed no significant seasonal differences in emission levels. In 2020, there was a slight trend towards higher emissions in the last quarter (see Figure 1).

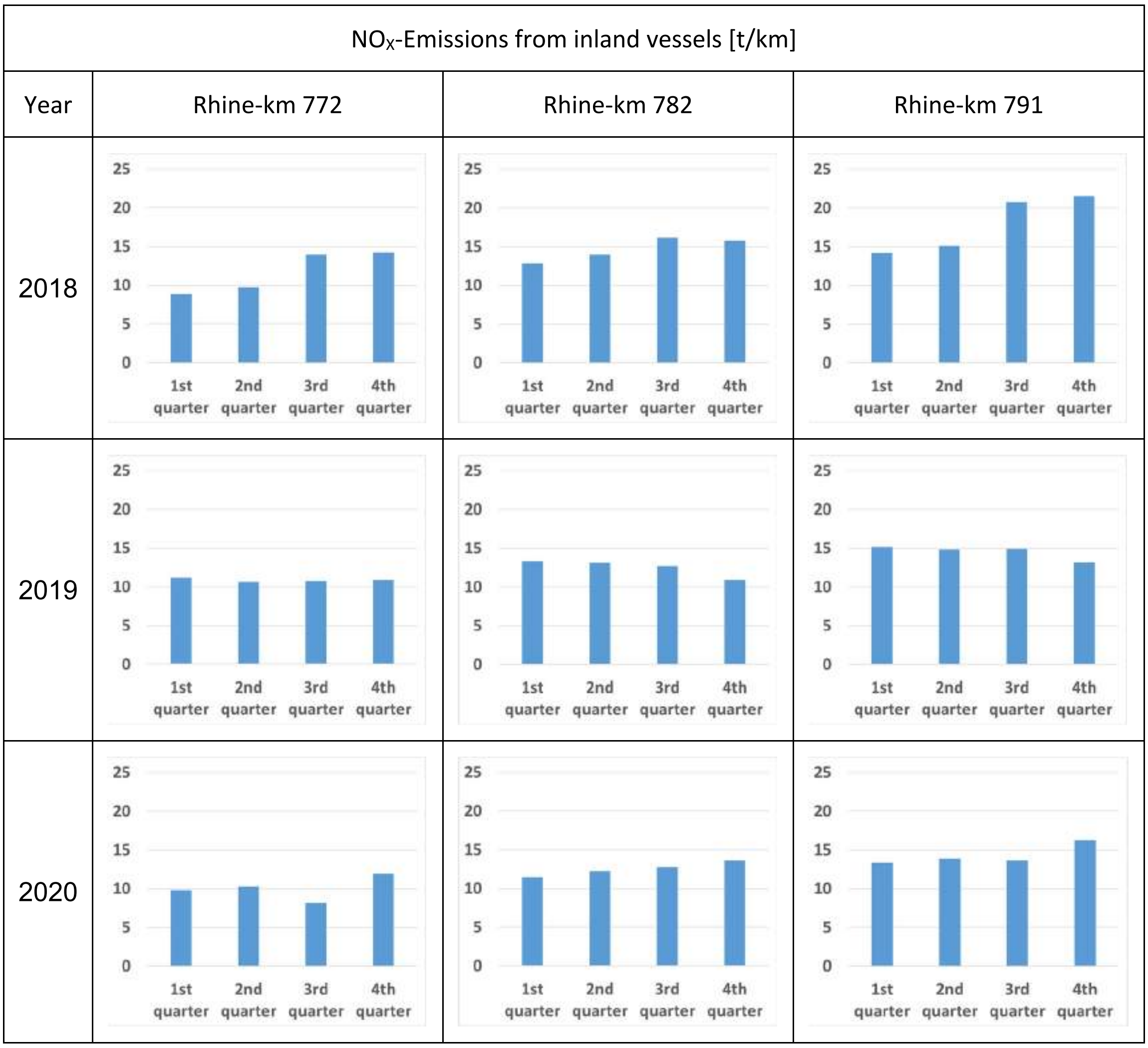


Figure 1: NO_X-Emissions per quarter over the course of the year in the Duisburg section of the Rhine. The measuring station DURH is located at Rhine-km 782.

3.2 *Calculation of emissions from ships sailing in the port area*

Usually there is no flow or only a very slight flow in the harbour basins and channels, so the emission factors derived for moving ships on the Rhine are not applicable for these cases. Therefore we derived a separate set of emission factors for port traffic (flow-free waters) from the measurements of the automatic measuring station in the port of Neuss (NERH).

The traffic in the ports was also recorded via the AIS-signals. The emission factors (onshore port) were also classified according to ship size and speed. The calculation of emissions had to be carried out separately for the individual port sections, as sections of the port waters, lying one behind the other, are used to different extents. To consider this, different line sources were defined for the harbour basins and harbour channels, which describe the travel path in the harbour area.

3.2.1 NO_X emissions from ships sailing in the port of Neuss

The line sources defined for the Neuss port area, which describe the routes in the port area, are shown in Figure 2. The contributions of the individual ships to the total emissions were added up separately for the differently coloured segments. In doing so, it was taken into account that only a fraction of all ships that enter the harbour sails to the outermost areas of the port. In Neuss, for example, all ships entering the port pass segment 0, whereas segment 13 (basin 1) is only passed by the ships actually travelling to basin 1.

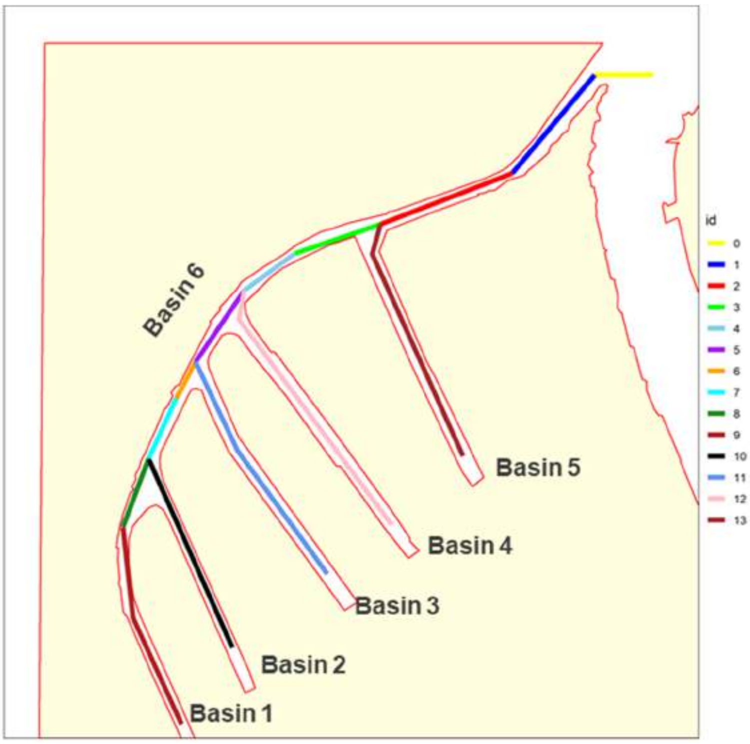


Figure 2: Segments of NO_X line sources for ships sailing in the port of Neuss

In the calculations for the emissions of the port area of Neuss, only pure port traffic needs to be considered. The total NO_X-emissions for the port of Neuss in 2018 caused by ships sailing in the port are 18,7 t NO_X (Table 3). The emission quantities have likely been of the same order of magnitude in 2019 and 2020.

Table 3: NO_X emissions of ships operating in the port of Neuss

Line source segment	NO_X-Emissions [t/a]	Line source segment	NO_X-Emissions [t/a]
Segment 0	1.6	Segment 7	0.4
Segment 1	3.5	Segment 8	0.3
Segment 2	3.8	Segment 9	0.9
Segment 3	1.6	Segment 10	0.2
Segment 4	1.0	Segment 11	0.4
Segment 5	0.6	Segment 12	2.0
Segment 6	0.2	Segment 13	2.1
		Total	18.7

3.2.2 NO_X emissions from ships sailing in the port of Duisburg

The line sources defined for the port area of Duisburg, which describe the route in the port area, are shown in Figure 3. For the differently coloured segments, the emission contributions of the individual ships were added up separately. Again, it was taken into account that only a part of the ships travels through the individual harbour basins. The shipping traffic in the port canal and in the Ruhr estuary, going to or coming from the locks, is also included here. The calculated emissions are listed in Table 4. Only the emissions directly associated with lock operation (short sections upstream and downstream of the lock with deceleration and acceleration phases, as well as the dwell time in the lock basin) were evaluated separately (see Chapter 3.4).

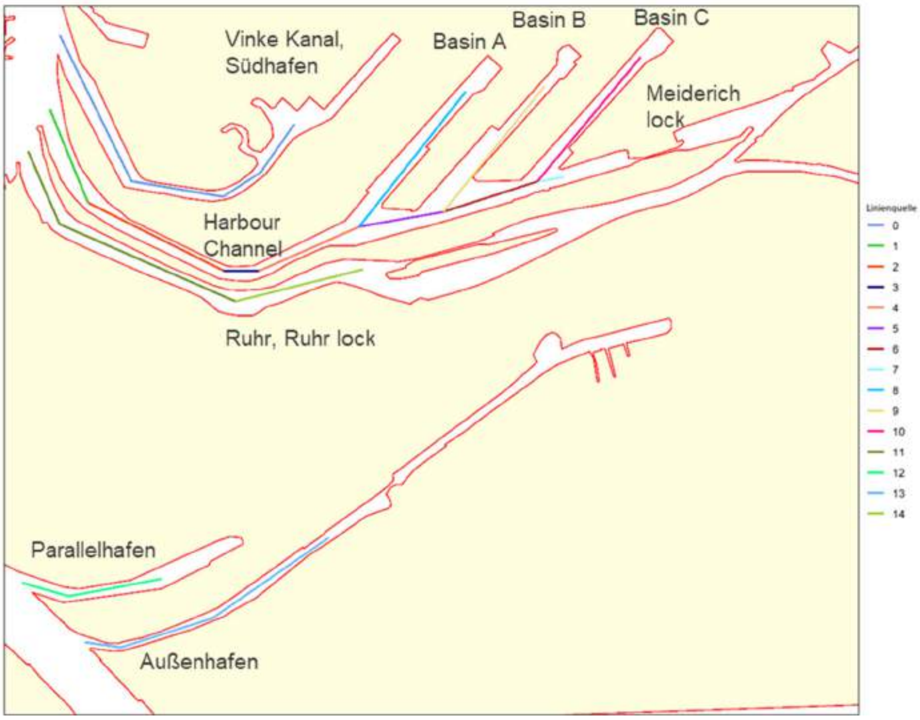


Figure 3: Segments of NO_X line sources for ships sailing in the port of Duisburg

The calculation of the emission quantities in the Port of Duisburg is more difficult, as there is additional transit traffic to the Ruhr lock and the Meiderich lock in the harbour canal and in the area of the mouth of the Ruhr. In 2018, it was about a total of 15,000 ships additionally sailing here (12,846 on the Harbour Channel, 2050 on the River Ruhr, see Table 5). For 2018, this resulted in a total of 41,3 t NO_X from ships travelling in the port and via the mouth of the Ruhr or the port canal to the locks.

Table 4: NO_X emissions of ships operating in the port of Duisburg incl. lock traffic

Line source segment	NO_X-Emissions [t/a]	Line source segment	NO_X-Emissions [t/a]
Segment 0	4.9	Segment 8	2.3
Segment 1	4.9	Segment 9	0.4
Segment 2	7.3	Segment 10	0.7
Segment 3	1.7	Segment 11	2.1
Segment 4	5.0	Segment 12	1.9
Segment 5	2.7	Segment 13	3.3
Segment 6	2.9	Segment 14	0.4
Segment 7	0.7		
		Total	41.3

3.4 Calculation of emissions resulting from lock activities

For the calculation of emissions caused by lock operations, it has not yet been possible to derive suitable emission factors from onshore measurements. For the section of water about 600 m upstream and downstream of the lock (deceleration and acceleration processes as well as for the dwell time with the main engine running in the lock chamber), which is crucial for lock operation, a different method for calculating the emissions had to be chosen. Therefore, the emission calculation for the lock operation was carried out with the updated and improved **LuWas** model [3] of the German Federal Institute of Hydrology **(Bundesanstalt für Gewässerkunde, BfG)**.

3.4.1 Ship traffic to the locks

The "Meiderich" and "Ruhrschleuse" locks, located in the Duisburg port area, connect the Rhine with the Rhine-Herne Canal (RHK). In 2018, a total of 12,846 inland vessels and pushed convoys as well as 1,684 pleasure crafts were channelled through the Meiderich lock. Access is via the Duisburg harbour canal. A total of 2,050 inland vessels and pushed convoys as well as 76 pleasure crafts were channelled via the less frequented Ruhr lock. Access is via the mouth of the Ruhr (see Figure 3).

Table 5: Vessels passing the locks in2018 according to data from the WSA “West German Canals”.

Type of ship	Name of lock: Schleuse Meiderich												
	Lockings in 2018												
	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Total
Freight vessel	524	636	799	694	633	596	818	925	878	99	--	--	6589
Freight vessel couple unit	58	55	96	91	105	70	87	87	65	9	--	--	723
Tanker vessel	573	593	616	555	526	507	620	732	641	65	--	--	5482
Tanker vessel vouple unit	2	4	5	4	2	10	10	14	1	--	--	--	52
Professional navigation													12846
Sport boats													1684
Type of ship	Name of lock: Ruhrschleuse												
	Lockings in 2018												
	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Total
Freight vessel	141	215	244	217	202	171	40	0	0	15	143	98	1486
Freight vessel couple unit	2	11	20	12	14	23	2				1		89
Tanker vessel	47	50	56	68	82	84	17			2	44	26	475
Tanker vessel vouple unit	--	--	--	--	--	--	--	--	--	--	--	--	--
Professional navigation													2050
Sport boats													76

3.4.2 Emissions in locks calculated with the new LuWas model.

LuWas is the emission model for inland vessels used by the German Federal Institute of Hydrology (BfG). In 2020 it has been updated by the engineering Lohmeyer GmbH on behalf of the BfG. This model provides emission calculations for ships sailing with constant speed, for ships approaching or leaving a berth/harbor or lock, for ships at berth or ships during locking operation. The fleet is divided into ship classes to accommodate various ship types. The model is based on the calculation of the average emissions per ship for each ship class. To determine the total emissions, the average values are multiplied by the number of ships, travelling on a given segment.

The modelling of emissions with **LuWas** is based on emission factors and applied power. The average power consumption of a ship class is calculated based on several parameters, e.g. sailing pattern (e.g. approaching a lock), ship size, nominal installed power, idle factor, water depth, speed over ground, water flow rate and ship load. Parameters depending on the ship type (e.g. total weight, flow resistant coefficient) are provided with default values (Lohmeyer 2020, Aktualisierung und Erweiterung des softwarebasierten Modells LuWas zur Ermittlung der schifffahrtsbedingten Luftschadstoffbelastung an Wasserstraßen, p. 47), but can be modified. On the other hand, parameters also depending on the waterway (e.g. speed over ground, water flow rate, water depth, waiting time in front of lock, locking duration), have to be entered before the calculation for each waterway segment. For the emission calculations in locks, presented in this paper, the ship class values are used according to the CEMT classification.

In order to calculate the emissions in and around a lock, the process of a ship's passage through the lock is divided into three phases: the approach (deceleration process), the lock process itself (main engine idling) and the exit from the lock (acceleration process). Each phase is modelled by a line segment and the emissions are distributed along this line.

For each phase different steps are modelled. Each segment has to be long enough to accommodate the modelled steps. In the following, the modelled process in **LuWas** of a ship passing a lock is shown in detail.

Approaching a lock

1. The ship reaches the beginning of the approach with its travel speed.
2. The ship reduces its velocity only with the flow resistance, the motor idles. The target speed is 0 km/h.
3. If the target speed of 0 km/h cannot be reached by flow resistance alone, the motor is put in reverse with 80% of its nominal power. (This step is only required if the segment length for deceleration is too short to come to a standstill in front of the lock just by flow resistance)
4. The ship waits for a given amount of time in front of the lock, the motor idles.
5. The ship accelerates with 80% of its nominal power to 3 km/h and proceeds to enter the lock.

In a lock

1. The ship continues to the center of the lock with 3 km/h.
2. The motor is put in reverse with 80% of its nominal power until the ship comes to a full stop.
3. During the operation of the lock, the motor idles.
4. After the locking procedure is completed, the ship accelerates with 80% of its nominal power to 3 km/h and leaves the lock.

Leaving a lock

1. After passing the lock doors, the ship accelerates with 80% of its nominal power to its travel speed.
2. If travel speed is reached before the end of the segment, the ship continues with travel speed.

This process is modelled for each ship class considered. The emissions of all ship classes are added up to the emissions of a lock. In cases of two-way traffic, the line segment for an approaching ship is the same segment as for a ship leaving the lock in the opposite direction.

The **LuWas** model uses reference year-specific emission factors for the ship engine fleet, with which the development scenarios for the ship engines in operation are to be mapped. Thus, by means of the programme, a situation for the reference year 2015 as well as for 2020 could be mapped. The expected emissions for 2018 were determined by interpolating the emission quantities of the two reference years. Based on the calculations, the Meiderich lock emitted 18.2 t NO_X and 480 kg PM_{10} in 2018 (Table 6). In total, 26.2 t NO_X were emitted at both locks in 2018.

Table 6: Ships' emissions at the Meiderich lock

Lock Duisburg Meiderich		NO_X (t/a)		
		2015	2018	2020
	Length	calculated	interpolated	calculated
Upper water	600 m	5.73	5.46	5.29
Lock basin	211 m	6.04	5.76	5.57
Lower water	600 m	7.96	7.60	7.35
		PM_{10} (kg/a)		
Upper water	600 m	151	141	134
Lock basin	211 m	158	147	139
Lower water	600 m	207	192	183

3.5 Georeferencing of NO_X emissions from moving vessels

For both port areas, extensive special measurement programmes on NO_2 pollution of the air were carried out within the CLINSH-project. A detailed summary of the results can be found in the CLINSH report of the LANUV *"Harbour Monitoring Part A: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf. Immission-side effect of emissions from shipping and port operations on nitrogen oxide pollution"* (2).

In order to be able to quantitatively assess the share of ships in the existing air pollution, detailed modelling is carried out in the form of pollution root cause analyses. For these modellings, the emission sources must be georeferenced as point, line or area sources. Figure **4** - Figure 6 show the NO_X emissions from moving ships.

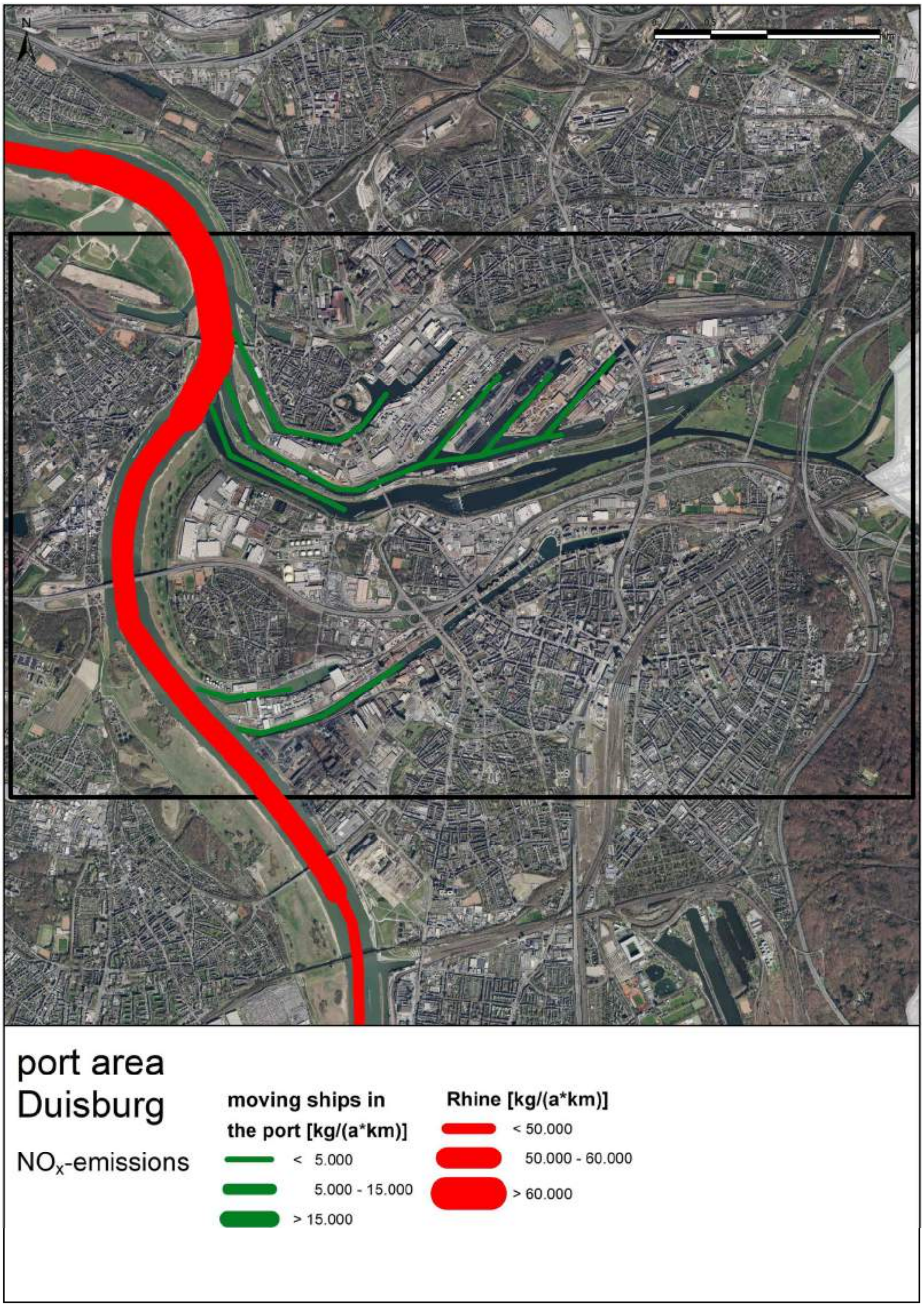


Figure 4: NO_X emission densities of the moving ships in the Duisburg study area

Inner box: Boundary of the port area

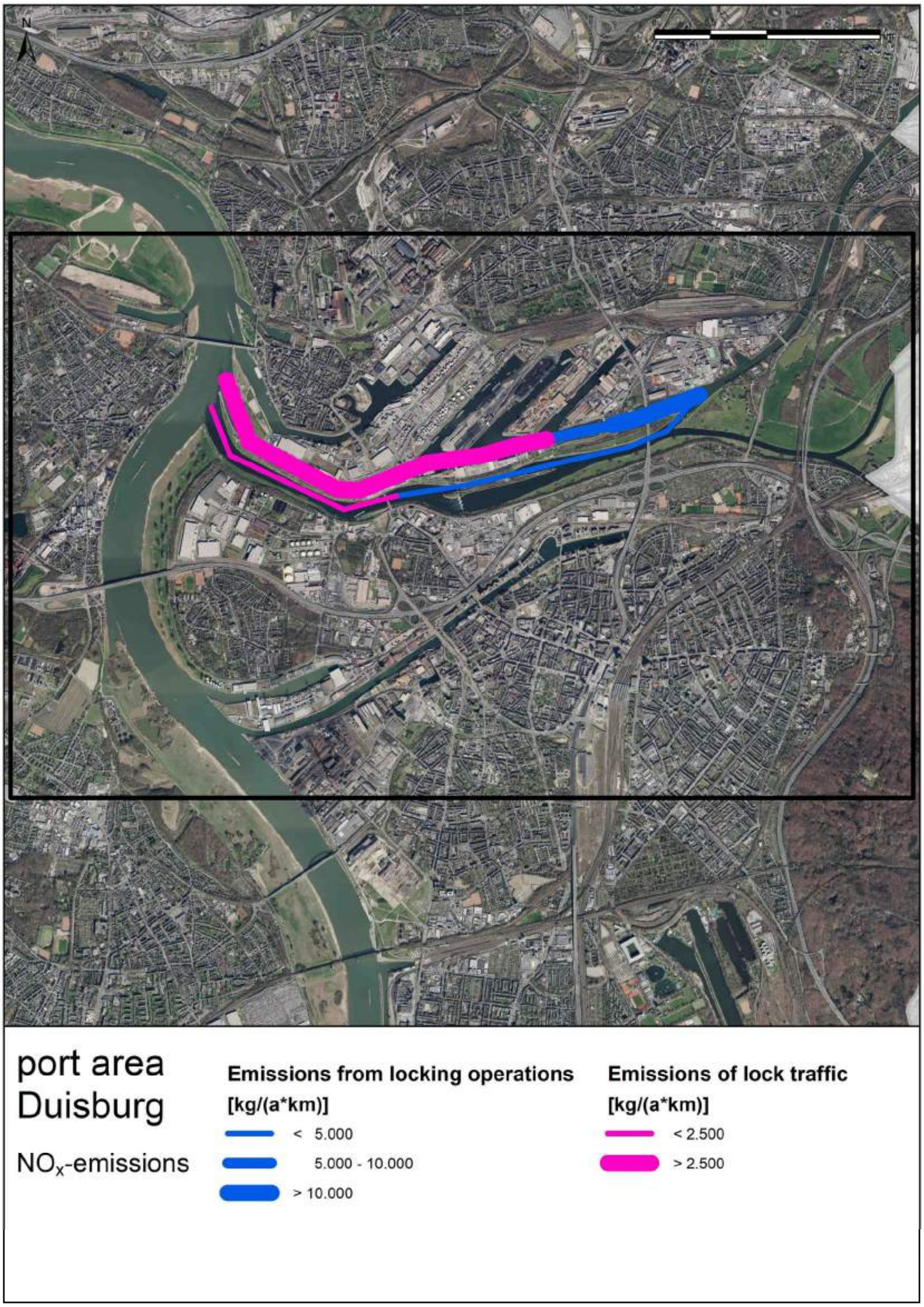


Figure 5: NO_X emission densities of the ships travelling to the locks and the lock operations in the Duisburg study area.
Inner box: Boundary of the port area

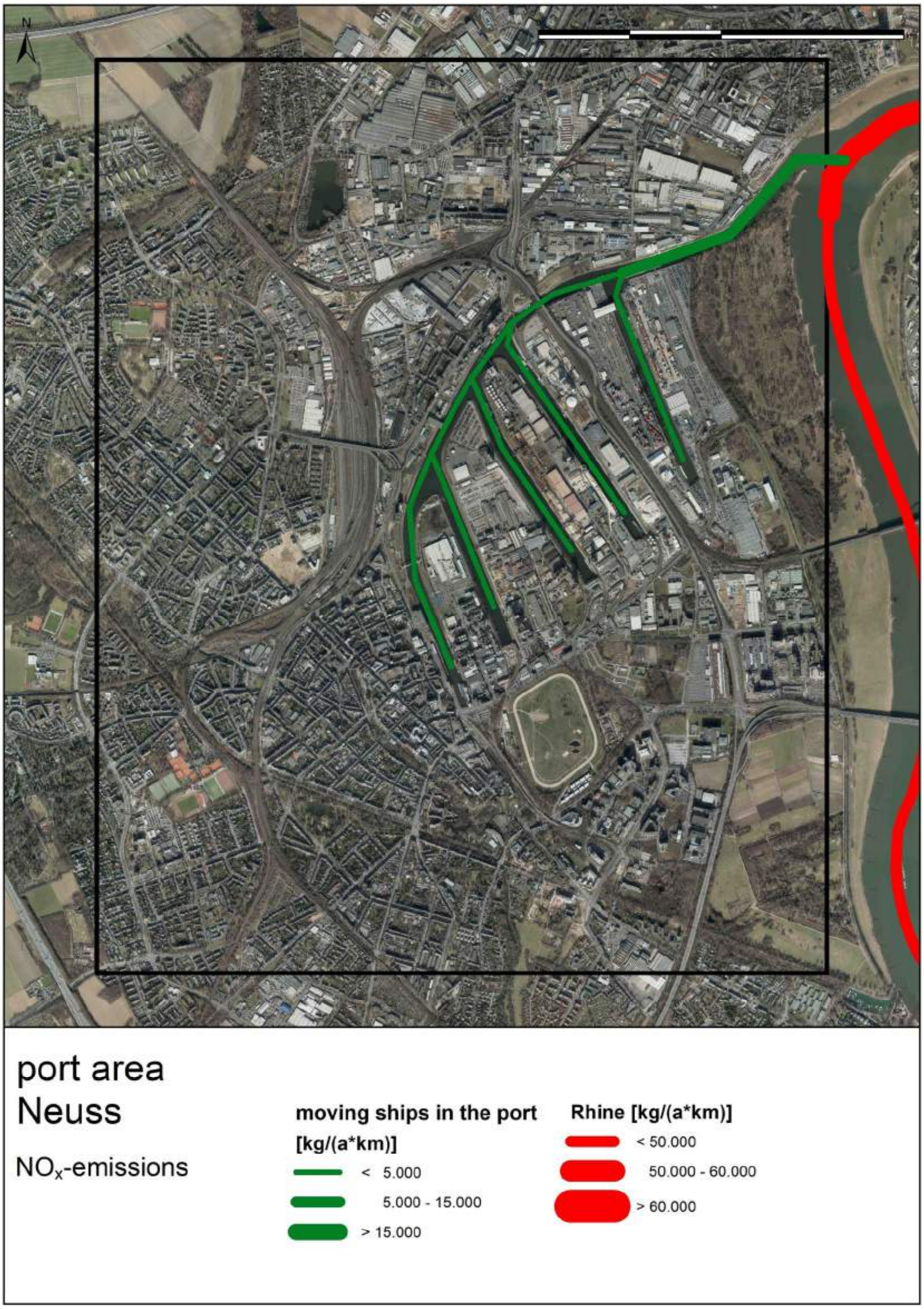


Figure 6: NO_X emission densities of moving ships in the Neuss/Düsseldorf study area
Inner box: Boundary of the port area

4. Emissions from ships at berth in the port

4.1 Input variables and description of the calculation methods

When determining emissions in ports, it must be taken into account that ships not only emit pollutants while underway, but that a non-negligible contribution to air pollution is also caused by ships at berth that ensure their power supply via the generators on board. The basics of the emission determination for these amounts are explained in the CLINSH report "*Harbour Monitoring Part B: Determination of NO_X-and particulate matter emissions from inland vessels at berth*" [(2)] and in the LANUV technical report 119 [(2a)]. For this contribution, the therein-described methodology was used for the study areas in Neuss and Duisburg.

Literature research and interviews have shown that cargo ships have a power demand of about 2 kW (P_{berth}) during the berthing period. This is provided by the "smallest" generators installed on board.

Since it is not possible to determine the number of generators for each individual ship at berth and to calculate the emissions individually, the emission factors of the "average fleet generator" were used to calculate the emissions of the ships at berth. The evaluation of the ZBDD data set for the "smallest" generators on board of the various ship classes with regard to the average output showed a homogeneous picture for both tankers and cargo ships.

Tankers predominantly have "smallest" generators with an output of 37 kW to 74 kW and cargo ships have "smallest" generators with an output from the output group of 28 kW to 36 kW.

Based on the emission factors listed in TREMOD[(6)] and the composition of the generator pool, an average emission factor for an "average smallest fleet generator" was derived for cargo and tanker ships respectively, which can be used for the emission calculation for the current inland navigation fleet. The derivation of the emission factors of the "fleet generators" for tankers and cargo ships was summarised in Table 7 and

Table ***8***.

The analysis of the ZBBD files[(5)] showed that tankers predominantly have "smallest" generators with an output between 37 kW and 74 kW and most cargo ships have "smallest" generators with an output from the output group between 28 kW and 36 kW. The composition of the generator pool on the ships was determined with the evaluation of the ZBBD-database. Based on the emission factors, listed in TREMOD[(6)] and the composition of the generator pool, an average emission factor for an "average smallest fleet generator" was derived for both cargo and tanker vessels, which can be used for the current inland navigation fleet for the calculation of emissions.

4.2 Emissions from moored cargo and tanker vessels without ship-side loading activity

Since it is not possible to determine the number of generators and to calculate emissions for each individual ship at berth, the emission factors of the "average fleet generator" were used to determine the emissions of the ships at berth. The evaluation of the ZBDD dataset for the "smallest" generators on board of the different ship classes with regard to the average power showed a homogeneous picture in each case for both tankers and cargo ships.

A summary of the length classes of the ships is possible. The derivation of the emission factors of the "fleet generators" for tankers and cargo ships was summarized in Table 7 and

Table ***8***.

The emission quantities of the fleet generator are calculated for the respective air pollutant and the respective generator size according to the following formula:

$$E_{Flottengen} = \sum_i e_{Generator_i} \cdot f_{EStufe_i} \cdot P_{Liege}$$

Where "i" is the index for the respective emission level. This results in the emission quantities shown in Table 7 and

Table ***8*** for the respective fleet generator:

Table 7: Estimation of NO_X emissions from the power generators of cargo ships and tankers at berth without shipboard loading activity, using the composition of the emission levels of the "smallest" generators.

Cargo vessels: "smallest" generator 28-36 kW, 2 kW/h							
NO_X	Share of fleet	Basic data per stage	Generator per 2 kWh	Share of emissions to "Fleetgenerator"	1 ship	50 Ships	
Emission level according to TREMOD	%	g/kWh	g/ 2kWh	g/kWh	g/8h	kg/8h	t/a
before 1981	38,4	31,5	63	12,1	193,5	9,7	3,5
1981-1990	5,9	33,6	67,2	2,0	31,7	1,6	0,6
1991-2002	12,6	19,6	39,2	2,5	39,5	2	0,7
∑ EU II + ZKR I	18,1	13	26	2,4	37,6	1,9	0,7
∑ EU IIIa + ZKR II	24,6	12,2	24,4	3,0	48,0	2,4	0,9
EG V since 2018	0,2	8,5	17	0,02	0,272	0,01	0,01
Basic data for calculation	Emissions "Fleet generator"			g/kWh 21,9	g/8h 350,7	kg/8h 17,5	t/a 6,4
Tanker vessels: "smallest" generator 37-74 kW; (Ship classes IV, Va, Vb = 85 - 135 m), 9 kW/h							
NO_X	Share of fleet	Basic data per stage	Generator per 9 kWh	Share of emissions to "Fleetgenerator"	1 ship	50 Ships	
Emission level according to TREMOD	%	g/kWh	g/ 9kWh	g/kWh	g/8h	kg/8h	t/a
before 1981	7,0	11,4	102,6	0,8	57,5	2,9	1,0
1981-1990	4,1	13,4	120,6	0,5	39,6	2,0	0,7
1991-2002	13,1	19	171	2,5	179,2	9,0	3,3
∑ EU II + ZKR I	53,3	9,1	81,9	4,9	349,2	17,5	6,4
∑ EU IIIa + ZKR II	22,5	6,3	56,7	1,4	102,1	5,1	1,9
EG V since 2018	--	3,5	--	--	--	--	--
Basic data for calculation	Emissions "Fleet generator"			g/kWh 10,1	g/8h 727,5	kg/8h 36,4	t/a 13,3

Table 8: Estimation of PM (particulate matter) emissions from the power generators of moored cargo vessels and tankers without shipside loading activity, using the emission levels of the "smallest" generators.

Cargo vessels: "smallest" generator 28-36 kW, 2 kW/h							
PM	Share of fleet	Basic data per stage	Generator per 2 kWh	Share of emissions to "Fleetgenerator"	1 ship	50 Ships	
Emission level according to TREMOD	%	g/kWh	g/ 2kWh	g/kWh	g/8h	g/8h	kg/a
before 1981	38,4	3,5	7	1,3	21,5	1075,2	392,5
1981-1990	5,9	2,6	5,2	0,2	2,5	122,7	44,8
1991-2002	12,6	2,8	5,6	0,4	5,6	282,2	103
∑ EU II + ZKR I	18,1	0,7	1,4	0,1	2,0	101,4	37
∑ EU IIIa + ZKR II	24,6	0,7	1,4	0,2	2,8	137,8	50,3
EG V since 2018	0,2	0,03	0,06	0,00	0,00096	0,05	0,018
Basic data for calculation	Emissions "Fleet generator"			g/kWh 2,1	g/8h 34,4	kg/8h 1,7	kg/a 627,6
Tanker vessels: "smallest" generator 37-74 kW; (Ship classes IV, Va, Vb = 85 - 135 m), 9 kW/h							
PM	Share of fleet	Basic data per stage	Generator per 9kWh	Share of emissions to "Fleetgenerator"	1 ship	50 Ships	
Emission level according to TREMOD	%	g/kWh	g/ 9kWh	g/kWh	g/8h	g/8h	kg/a
before 1981	7,0	2,7	24,3	0,2	13,6	680,4	248,3
1981-1990	4,1	1,9	17,1	0,1	5,6	280,4	102,4
1991-2002	13,1	1,3	11,7	0,2	12,3	613,1	223,8
∑ EU II + ZKR I	53,3	0,4	3,6	0,2	15,4	767,5	280,1
∑ EU IIIa + ZKR II	22,5	0,4	3,6	0,1	6,5	324,0	118,3
EG V since 2018	--	0,02	--	--	--	--	--
Basic data for calculation	Emissions "Fleet generator"			g/kWh 0,7	g/8h 53,3	kg/8h 2,7	kg/a 972,9

The quantity of the respective pollutant emitted by a ship in a port can be determined via the berthing time (t) of a ship and the emission value of the corresponding fleet generator from Table 7 and

Table ***8***. The total amount of pollutants emitted is the sum of the emissions of all ships that have been in the port.

The number of ships (n_ship) for the year 2018 served as the database for the emission calculation. In the first step, the AIS data of the ships from the respective port areas were evaluated. We also asked the port operators about the officially registered amount of ships. It turned out that the evaluations of the AIS signals resulted in implausibly high numbers of ships, approximately twice the number for the lying ships. There is still a need for further development to analyse the number of moored ships by means of AIS signals.

The AIS data were scaled based on the official ship numbers. This was necessary because the spatial distribution of the individual ships in the port, the size class of the individual ships and the berthing time (t [h]) per port basin and ship class could be determined from the AIS signals. This information could not be provided by the port operators in the required level of detail. Therefore, information from the evaluation of the AIS signals was scaled with the number of ships provided by the port operators. Table 9 shows how the ships are distributed across the port basins of the ports of Duisburg and Neuss.

This provides a data set that maps each individual ship as a point source at the corresponding berth position. These point clouds reveal that the ships cluster in certain sections of the harbour basins. These clusters can best be characterized as line sources.

In order to combine the individual point sources into line sources, the individual basins of the respective ports were divided into a grid and the ships located within each individual grid cell were counted. Figure 7 (Duisburg) and Figure 9 (Neuss/Düsseldorf) show in which grid cells the ships were located in the respective port. Figure 8 and Figure 10 show the resulting groupings of the berthing ships to line sources and the corresponding allocation of the point sources to the respective line sources.

Table 9: Percentage distribution of ships among the port basins

Research area	Basin	Percentage of ships in the respective port basin. [%]
Duisburg	Südhafen/Vinckekanal	26.0
	Basin A	22.2
	Basin B	3.7
	Basin C	7.4
	Harbour channel	7.4
	Ruhr mouth	7.4
	Außenhafen	3.7
	Parallelhafen	22.2
Neuss	Basin 1	10.1
	Basin 2	2.7
	Basin 3	7.4
	Basin 4	19.0
	Basin 5	12.2
	Basin 6	48.6

According to the information on the numbers of ships provided by the port operators

The subsequent emission calculation was carried out separately for each ship. The corresponding "smallest fleet generator" is assigned to each ship, depending on whether it is a cargo ship, a tanker (without its own loading activity) or another type of ship. Subsequently, an allocation of the corresponding emission from Table 7 and

Table ***8***, whereby in the latter case the basin of the port in which the ship was located, was also taken into account.

The product of emission quantity per time unit and berthing time results in the emission contribution for each individual ship. The emissions of the ships of the respective assigned line source are then added up. In order to take into account the number of ships provided by the port operators, the emissions were subsequently scaled linearly. The percentage distribution of the ships of the individual line sources (determined from the AIS data) (Table 9) was transferred to the official numbers of ships of the port operators in order to achieve a more realistic allocation of the official numbers of ships to the line sources.

The percentage distribution of the ships to the individual segments in the harbour basins determined in this way is compiled in Table 10 and Table 11. With the ship numbers determined in this way, the emissions of the lying ships per segment were determined (see Table 15, p. 35).

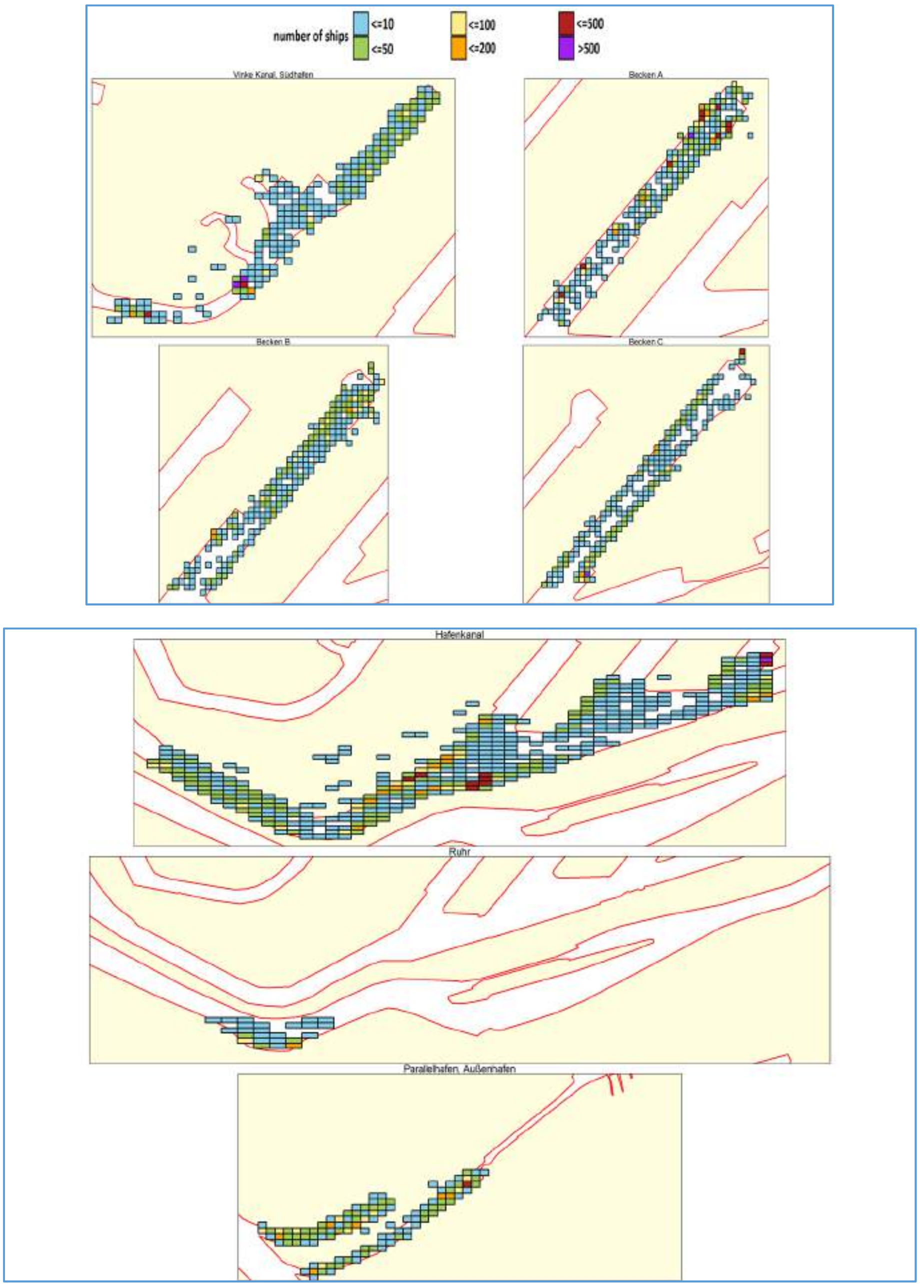


Figure 7: Overview of the partitioning of the individual basins of the Port of Duisburg into a grid.
The grid cells, in which berthing positions of ships were registered, are shown. The fill colour indicates how many ships were in the respective grid cell.

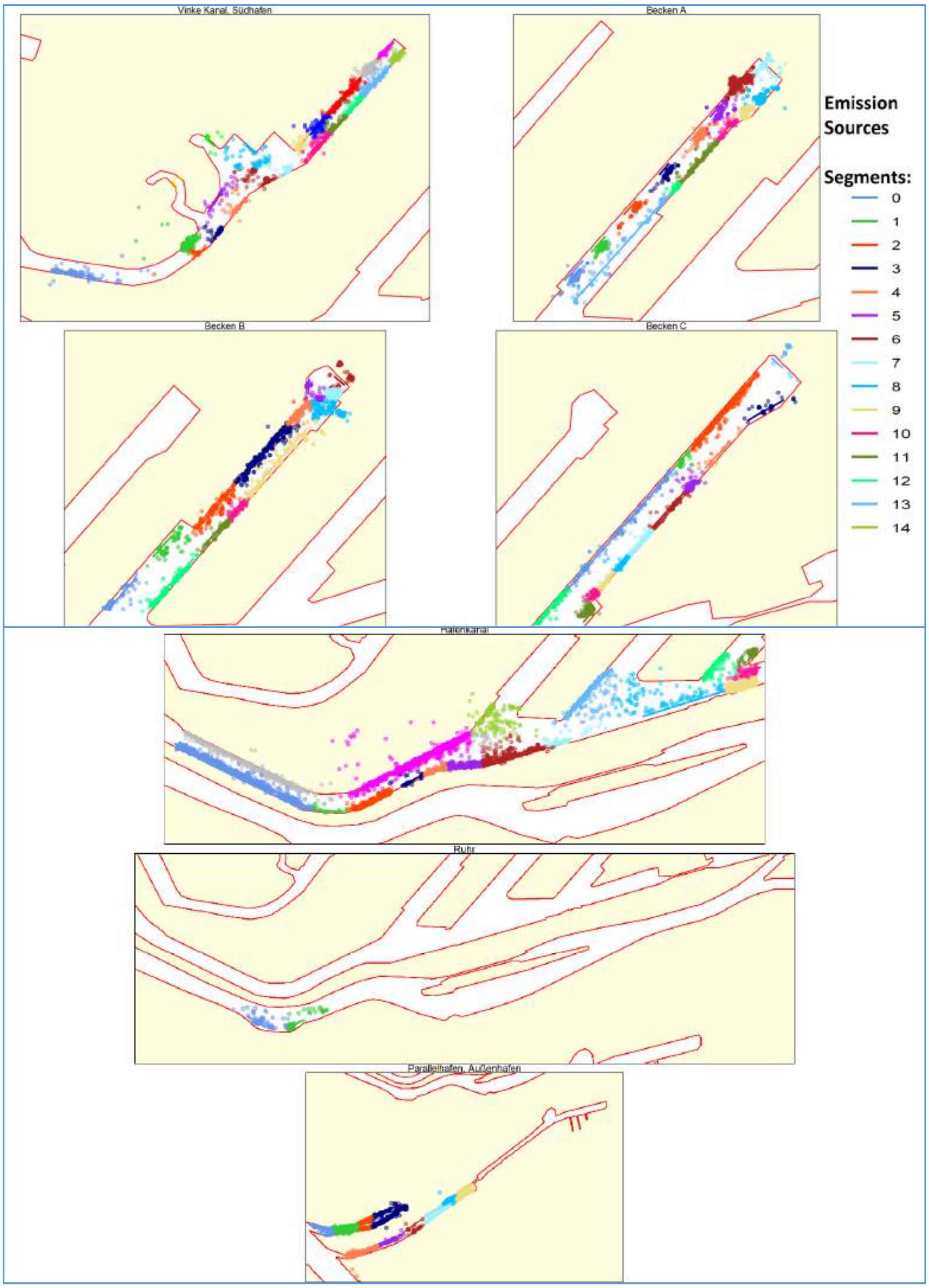


Figure 8: Allocation of the point data of the individual ships to the respective line sources (Port of Duisburg).

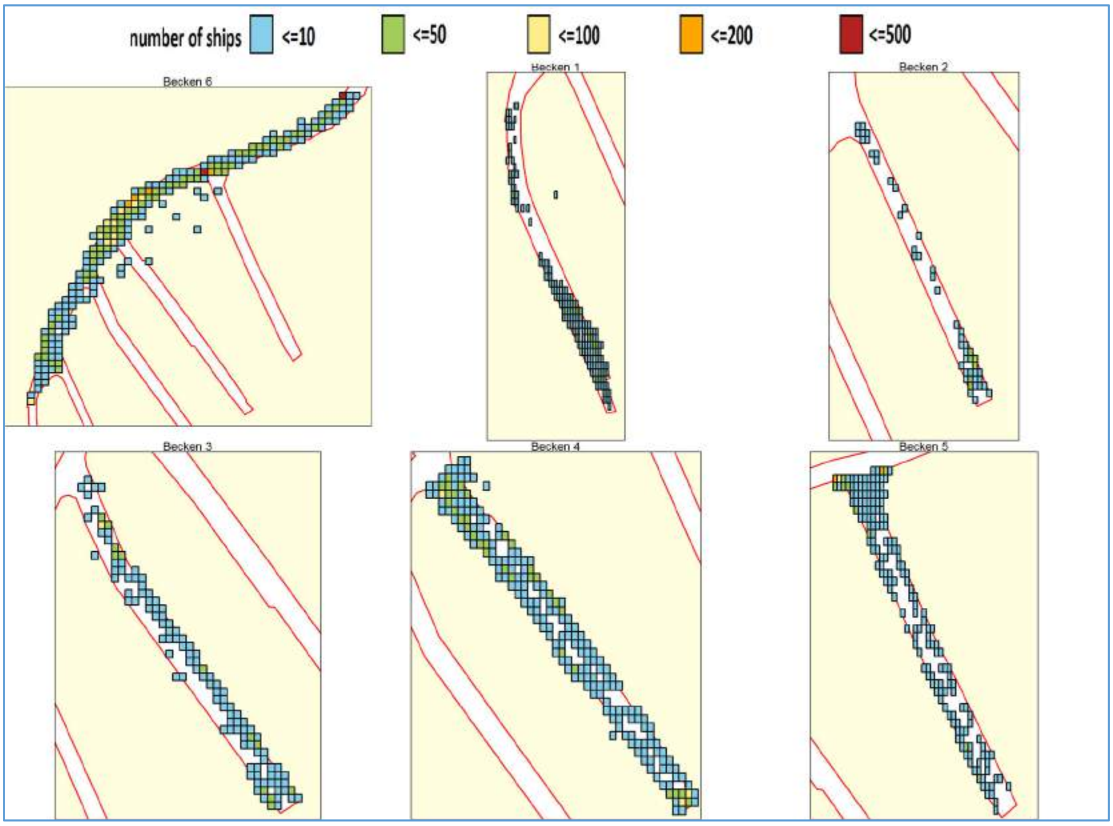


Figure 9: Overview of the partitioning of the individual basins of the Port of Neuss into a grid.
The grid cells, in which berthing positions of ships were registered, are shown. The fill colour indicates how many ships were in the respective grid cell.

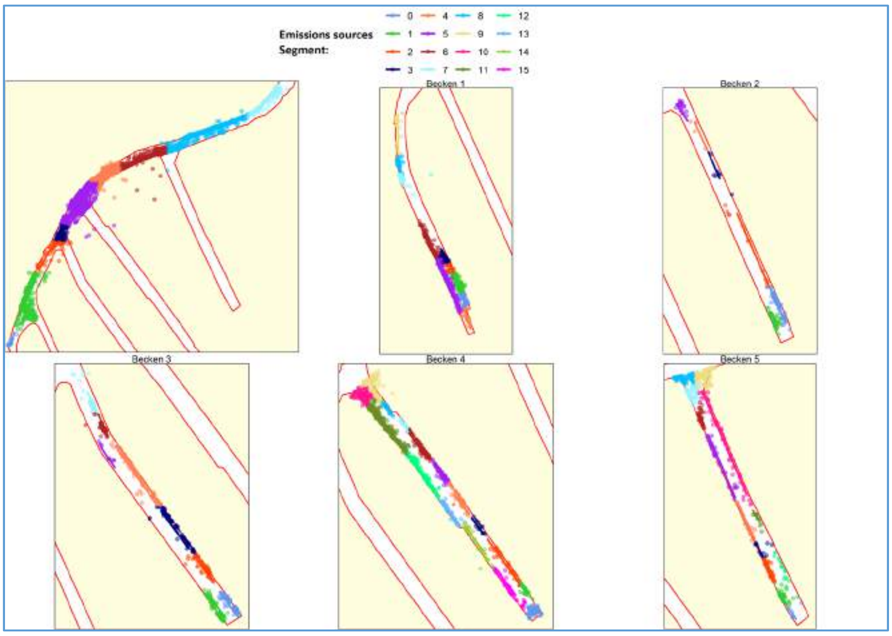


Figure 10: Allocation of the point data of the individual ships to the respective line sources (Port of Neuss).

Table 10: Share of ships [%] of the respective basin in the Port of Duisburg accounted for by the corresponding line source (LQ).

Harbour	Line source	Südhafen/ Vincke-kanal	Basin A	Basin B	Basin C	Harbour channel	Ruhr-mouth	Außen -hafen	Parallel-hafen
Duisburg	Segment 0	16.9	6.6	2.9	5.6	9.9	49.3		24.6
	Segment 1	40.6	6.8	11.3	5.5	0.2	50.7		23.9
	Segment 2	4.1	4.1	8.1	12.8	4.2			19.5
	Segment 3	1.9	4.0	16.8	1.1	0.6			32.0
	Segment 4	1.0	5.9	9.1	0.6	3.6		23.3	
	Segment 5	1.3	15.8	4.3	3.0	8.3		7.0	
	Segment 6	4.1	21.8	4.0	2.5	10.8		2.6	
	Segment 7	0.8	4.0	7.2	3.2	0.7		10.9	
	Segment 8	1.5	15.7	17.1	3.2	1.0		20.9	
	Segment 9	1.9	8.1	7.4	2.4	5.4		35.4	
	Segment 10	2.1	2.0	4.0	4.5	1.5			
	Segment 11	2.3	1.9	3.1	39.5	17.0			
	Segment 12	1.4	1.6	4.6	3.9	2.0			
	Segment 13	4.4	1.7		12.0	3.5			
	Segment 14	2.2				4.1			
	Segment 15	1.0				22.7			
	Segment 16	3.9				4.5			
	Segment 17	5.0							
	Segment 18	2.2							
	Segment 19	1.4							
	Segment 20	0							
	Total	100	100	100	100	100	100	100	100

Table 11: Share of ships [%] of the respective basin in the port of Neuss accounted for by the corresponding line source (LQ).

Harbour	Line source	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6
Neuss	Segment 0	8.4	46.9	9.5	15.5	1.7	1.6
	Segment 1	19.9	28.5	17.7	2.0	5.2	7.8
	Segment 2	2.7	5.8	14.5	2.5	5.3	1.8
	Segment 3	9.8	3.4	15.2	0.9	1.1	2.5
	Segment 4	10.0	2.4	13.7	2.9	2.6	21.1
	Segment 5	26.3	13.4	1.9	9.0	4.5	24.8
	Segment 6	9.7		9.6	6.8	3.7	16.0
	Segment7	5.7		17	2.3	6.7	11.6
	Segment 8	5.0			1.7	35.3	12.7
	Segment 9	2.5			8.7	25.5	
	Segment 10				11.5	6.3	
	Segment 11				17.0	1.3	
	Segment 12				6.8	1.1	
	Segment 13				5.4		
	Segment 14				2.5		
	Segment 15				4.5		
	Total	100	100	100	100	100	100

4.3 *Emissions from tanker vessels with ship-side unloading activity*

The unloading of tanker vessels is usually carried out by on-board pumps. Tanker vessels calling at the tank farms at Duisburg and Neuss mainly belong to the size classes IV (85m), Va (110m) and Vb (135m). For these vessels, a power of about 110 kW is required to operate the vessel and the on-board pumps, which is covered by the largest generator on board. The possible discharge capacity (m^3/h) depends on the respective intake capacity of the shore facility. Thus, the respective unloading time of the ships depends on both the cargo volume of the ship and the intake capacity of the shore facility. The calculation of the emissions of the tankers during the unloading process is carried out using the TREMOD base emission factors for mobile diesel engines of the power class 130-299 kW.

Emissions from tankers without unloading activity are calculated using TREMOD[5] baseline factors for the 27-74 kW power class, adjusted for low load (Table 7 and

Table 8).

4.3.1 *Emission behaviour of the "largest" generators on tankers*

Table 12 summarizes the baseline emissions (TREMOD) for estimating NO_X and PM emissions from the "largest" fleet generators (130-299 kW power class) of tankers of the length classes IV, Va and Vb. Analogously to the procedure for the “smallest” generators, the emission values were also determined for the average "largest fleet generator" on tankers per hour of unloading activity with a power requirement of 110 kW.

Table 12: Estimation of NO_X and PM (particulate matter) emissions from the power generators of moored tankers with shipboard loading activity, taking into account the composition of the emission levels of the "largest" generators.

Tanker vessels: "largest" generator 130-299 kW; (Ship classes IV, Va, Vb = 85				
NO_X	**Share of fleet**	**Basic data per stage**	**Share of emissions to "Fleetgenerator"**	
Emission level according to TREMOD	%	g/kWh	g/kWh	g/110 kWh
before 1981	**6,6**	17,8	1,2	129,2
1981-1990	**3,7**	12,4	0,5	50,5
1991-2002	**10,7**	11,2	1,2	131,8
∑ EU II + ZKR I	**42,4**	5,2	2,2	242,5
∑ EU IIIa + ZKR II	**36,6**	3,2	1,2	128,8
EG V ab 2018	**--**	--	--	--
Basic data for calculation	**Emissions "Fleet generator"**		**g/kWh 6,2**	**g/110kWh 682,9**
Tanker vessels: "largest" generator 130-299 kW; (Ship classes IV, Va, Vb = 85				
PM	**Share of fleet**	**Basic data per stage**	**Share of emissions to "Fleetgenerator"**	
Emission level according to TREMOD	%	g/kWh	g/kWh	g/110 kWh
before 1981	**6,6**	0,90	0,06	6,5
1981-1990	**3,7**	0,80	0,03	3,3
1991-2002	**10,7**	0,40	0,04	4,7
∑ EU II + ZKR I	**42,4**	0,10	0,04	4,7
∑ EU IIIa + ZKR II	**36,6**	0,10	0,04	4,0
EG V ab 2018	**--**	--	--	--
Basic data for calculation	**Emissions "Fleet generator"**		**g/kWh 0,21**	**g/110kWh 23,2**

4.3.2 *Calculation of emissions from real tanker traffic on the "oil island" in the Port of Duisburg for the year 2018.*

Mineral oil products and industrial chemicals are handled on the so-called "Oil Island" in the Port of Duisburg. The seven facilities for handling tankers are all located in port basin A. The facilities have a reception capacity of 400 m³/h each. The tankers are unloaded with the ship's own pumps, and loading is done with pumps from the shore facility.

In 2018, a total of 1,864 tankers visited the “Oil Island”. About 40% of the vessels belonged to size class IV (85 m) and 60% to size class Va (110 m). Smaller tankers cannot be handled at the facility. Class Vb (135 m) vessels call at the facilities only 1-2 times per month. Therefore, additional five unloading and twelve loading operations were included in the estimate. In 715 cases the ships were unloaded, in 1,149 cases the ships were loaded (Table 13).

Table 13: Unloading and loading operations in 2018 at the "Oil Island" in the Port of Duisburg

„Oil Island“	Loading activities		Ship class		
2018	Number	% share	IV	Va	Vb
		%	85 m (40 %)	110 m (60 %)	135 m
Unloadings	715	38,4	286	424	5
Loadings	1149	61,6	460	678	12
Total	1864				

The calculation of emissions from loading operations is analogous to the procedure for cargo motor vessels, using the number of berthing vessels, the average berthing time, a power requirement of 9 kW and the emission factors for the assumed average "smallest fleet generator" (TREMOD base emissions, low load, power 37-74 kW) (5) of the tankers (Table 7 and

Table 8).

Emissions from tankers during unloading operations (with generator use on board) are calculated using the number of loading operations per ship class, a power requirement of 110 kW, the number of average unloading times per ship class and emission factors for the average "largest fleet generator" (130-299 kW) (Table 12).

Since unloading requires an additional mooring of about 1 h for clearing in and out, an additional "emission surcharge" of 1 h was considered for each unloading process and runtime "smallest generator". For the loading operations, this time has already been considered in the time at berth. The calculation results were compiled in Table 14. In total, the 1,864 tankers, that were handled at the "oil island" in port basin A in 2018, emitted an emission quantity of 4.06 t NO_X and 145 kg PM.

Table 14: Estimation of the NO_X and PM emissions generated by the tanker vessels, loading or unloading at the “Oil Island” in port basin A in Duisburg for the year 2018.

Unloading operations with ship facilities Total: 715	Ship class	IV 85 m	Va 110 m	Vb 135 m
	Unloading time	6 h	9 h	12 h
Emissions per unloading	NO_X (kg) PM (g)	4,10 139,2	6,15 208,8	8,20 278,4
Unloading operations	Quantity	286	429	5
Emissions 2018	NO_X (kg) PM (kg)	1172,0 39,8	2637,1 89,6	41,0 1,4
Surcharge clearing (in/out) 1h "smallest" generator	NO_X (kg) PM (kg)	14,5 1,0		
Unloading	Ship's emissions Duisburg 2018 Tanker unloading operations in port basin A			
	NO_X (t) 3,86 PM (kg) 131,8			
Loading operations with shore facilities Total: 1149	Ship class	IV 85 m	Va 110 m	Vb 135 m
	Loading time	7 h	10 h	13 h
Emissions per loading	NO_X (g)	141,4	181,8	242,4
	PM (g)	9,8	12,6	16,8
Loading operations	Quantity	460	677	12
Emissions 2018	NO_X (kg) PM (kg)	65,04 4,5	123,08 8,5	2,91 0,2
Surcharge for clearing (in and out)	Already included in loading times			
Loading	Ship's emissions Duisburg 2018 Tanker loading operations in port basin A			
	NO_X (t) 0,19 PM (kg) 13,2			
2018	Ship's emissions Duisburg 2018 Tanker vessels at berth in the port basin A "Oil Island"			
	NO_X (t) 4,06 PM (kg) 145,0			

4.4 Georeferencing of emissions from moored cargo ships and tankers

For the modelling of the polluter root cause analyses for the measurement results at the measuring points of the special measurement programme for CLINSH, the emission characteristics of the source "ships at berth" must be determined and georeferenced. It turned out that the distribution of cargo ships in the harbour basins is very variable due to the mobility of most of the land-based loading devices (cranes, container gantry cranes). For modelling purposes, the representation as a line source is therefore most suitable.

Tankers are bound to fixed loading facilities that have to be called at. Therefore, for tanker emissions, a point source representation is most appropriate for modelling. Table 15a-c summarizes the determined emissions of the moored cargo ships in the individual port basins in Neuss and Duisburg. Figure 11 (Duisburg) and Figure 12 (Neuss) show the georeferenced distribution of ship emissions during berthing times for the port areas of Neuss/Düsseldorf and Duisburg.

Table 15a: Calculated emissions of the moored cargo ships for the individual port basins of the ports of Neuss and Duisburg.

Port	Becken	NO_X [t/a]	PM_{10} [t/a]
Duisburg	Südhafen/Vinckekanal	1,435	0,141
	Basin A	0,500	0,049
	Basin B	0,079	0,008
	Basin C	0,190	0,019
	Hafenkanal	0,255	0,024
	Ruhr mündung	0,323	0,032
	Außenhafen	0,997	0,098
	Parallelhafen	0,115	0,011
	Duisburg total	3,9	0,38
Neuss	Basin 1	0,803	0,078
	Basin 2	0,172	0,017
	Basin 3	0,301	0,029
	Basin 4	1,203	0,116
	Basin 5	0,513	0,050
	Basin 6	1,069	0,104
	Neuss total	4,1	0,39

Table 1b: Calculated emissions of the moored tanker vessels ships for the individual port basins of the ports of Neuss and Duisburg.

Port	Basin	NO_X [t/a]	PM_{10} [t/a]
Duisburg	Basin A	5,21	0,154
	Parallelhafen	1,52	0,055
	Ruhrmündung	4,91	0,180
	Duisburg total	11,6	0, 39
Neuss	Basin 1	0,31	0,013
	Basin 2	0,62	0,022
	Basin 3	2,19	0,078
	Basin 4	1,03	0,038
	Rheinkanal (Basin 6)	0,12	0,009
	Neuss total	4,0	0,16

Table 2c: Total emissions of the ships at berth in the ports of Neuss/Düsseldorf and Duisburg in 2018

2018	Duisburg		Neuss	
	NO_X (t)	%	NO_X (t)	%
Cargo vessels	4,0	26	4,3	52
Tanker vessels	11,6	74	4,0	48
Total	15,6		8,1	
	PM_{10} (t)	%	PM_{10} (t)	%
Cargo vessels	0,38	49	0,39	71
Tanker vessels	0,39	51	0,16	29
Total	0,77		0,55	

In 2018, a total of 15.6 t NO_X was emitted by ships at berth in the port of Duisburg. The approx. 3,000 tankers (approx. 20 % ship share) caused 74 % of the emissions. In addition, approx. 770 kg of particulate matter (PM_{10}) was emitted. The share of tankers to PM_{10} was about 50 %. In 2018, the emissions of the ships at berth in the port of Neuss were around 8.1 t NOX and 550 kg particulate matter.

A detailed description of the method for calculating emissions from ships at berth as well as more detailed calculation results can be found in the CLINSH report of the LANUV. (*"Harbour Monitoring Part B: Determination of NO_X and particulate matter emissions from inland vessels at berth"*)[(2)] as well as in the German-language technical report 119 of the LANUV [(2a)].

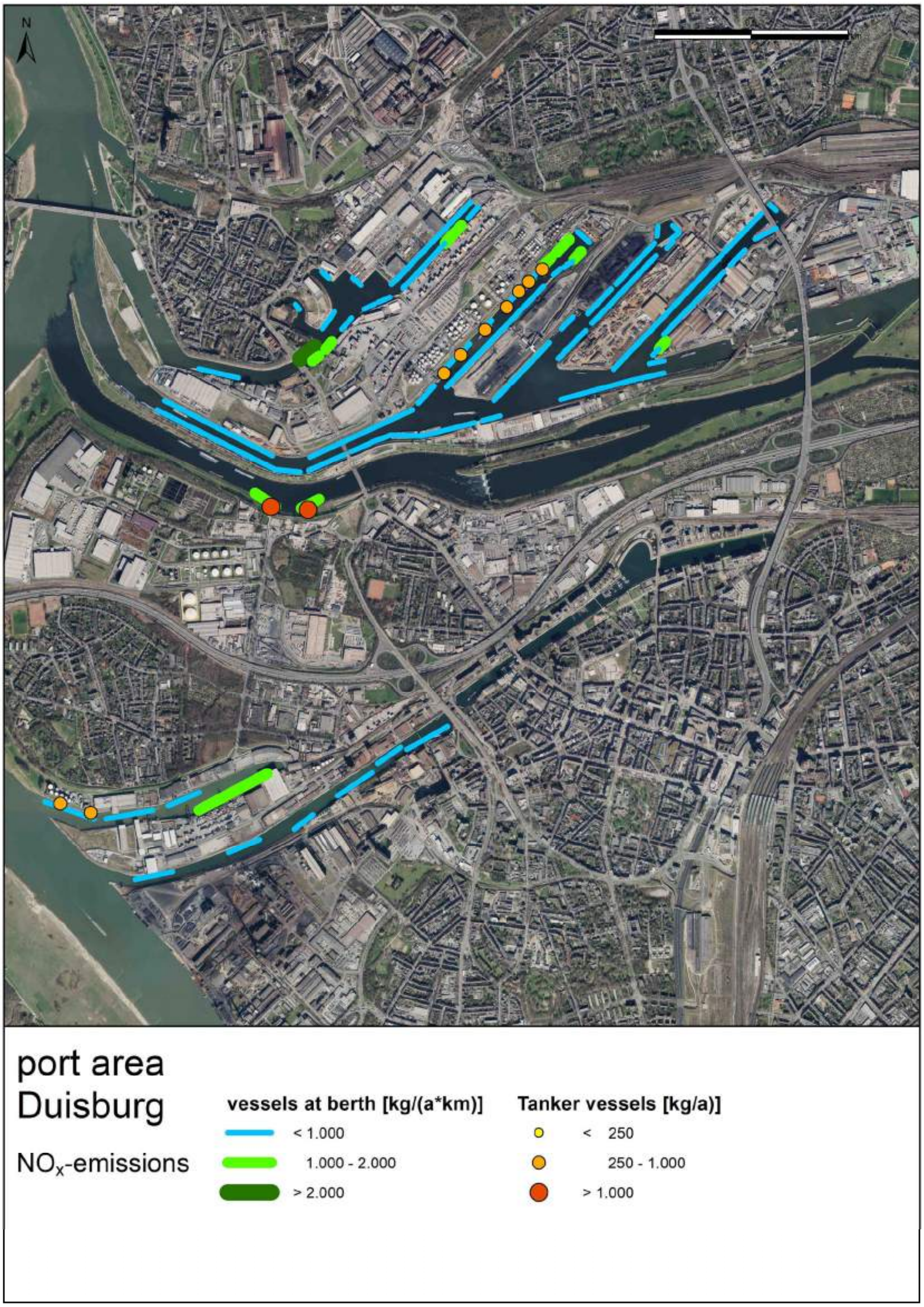


Figure 11: Emissions of moored ships as liner (cargo ships) and point sources (tankers) in the port area of Duisburg

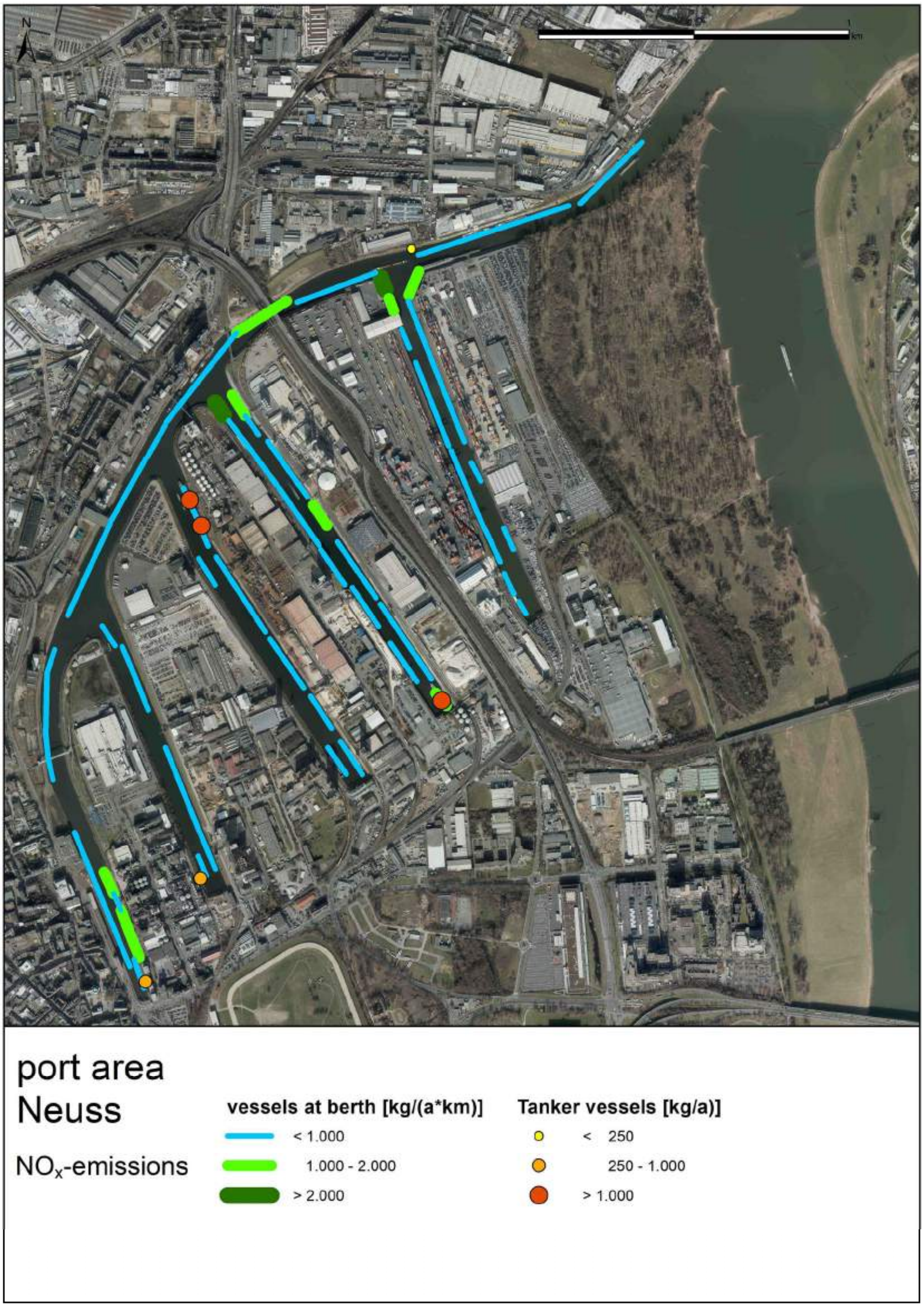


Figure 12: Emissions from moored ships as liner (cargo ships) and point sources (tankers) in the port area of Neuss

5. Emissions inventories from the emission cadasters of the state of NRW

In addition to the emissions from shipping traffic in the two ports and on the Rhine (cf. Chapters 3 and 4), the emissions of all other relevant emitter groups were determined or compiled from the current emission inventories of the State of NRW for the study area, which includes the two port areas of Duisburg and Neuss/Düsseldorf.

Installations requiring a permit are particularly likely to cause harmful effects on the environment through emissions of air pollutants. Such installations are listed in the Annex to the 4th Ordinance to the BImSchG (7).

According to the 11th BImSchV (8), operators of installations subject to licensing are obliged to specify air pollutants in terms of quantity, spatial and temporal distribution. The latest available data for Duisburg and Neuss/Düsseldorf come from the emission declarations for the declaration period 2016.

The emissions of the following emitter groups were taken into account from the current emission cadastres of the State of NRW:

- Industry
- Small combustion plants (HuK)
- Road traffic
- Air traffic
- Rail traffic
- Off-road

For road traffic in the study area, in addition to data from the state emission cadastre, current data from the work on the clean air plans for Neuss and Duisburg could be used. In addition, data on traffic loads from special surveys in the two port areas were available. Furthermore, within the port areas, emissions from the port railway, industrial trucks and vehicle loading were determined on the basis of detailed surveys.

Summarized explanations of the emissions from the emission cadastres of the state of North Rhine-Westphalia can be found in the following subchapters. The determination of emissions on the basis of further special surveys on road traffic and other emission sources in the port area is amplified in the following chapter six.

5.1 Industrial emitters in the Duisburg urban area

5.1.1 Plant structure in the Duisburg urban area (NO_X)

The urban area of Duisburg is characterised by strong industrialisation. A total of 201 installations subject to licensing are registered here, of which 164 must submit complete emission declarations in accordance with the 11th BImSchV [(8)]. The distribution of these installations among the upper groups of the 4th BImSchV [(7)] is shown in Figure 13.

Table 16 (NO_X emissions of the main groups of the 4th BImSchV in the urban area of Duisburg) illustrates the dominant role of the main groups 1 (heat generation, mining, energy) and 3 (steel, iron and other metals including processing) in the NO_X emissions. The major share of NO_X emissions accounted for the enterprises of the group "heat generation, mining, energy" (9.1 kt, 52 % of the emissions) and the group steel, iron and other metals (8.2 kt, 46.7 % of the emissions). Table 17 lists the 17 largest nitrogen oxide emitters at Duisburg

Figure 14 shows the distribution of NO_X emitters (> 50 t/a) across the city area. The large Duisburg steel sites of ***thyssenkrupp Steel Europe AG*** (Duisburg-Mitte/Nord) and Hüttenwerke Krupp-Mannesmann GmbH in the south of Duisburg are conspicuous here.

With these emission quantities, it must be taken into account that the largest share of NOX emissions is emitted via high stacks. Therefore, these quantities usually do not have a ground-level effect on air quality in the immediate urban area. They are transported in higher air layers over long distances (long-distance transport) with the air currents and only lead to an increase in background pollution at a great distance. When considering the effect of emission sources on air pollution along waterways, low nearby sources are particularly relevant.

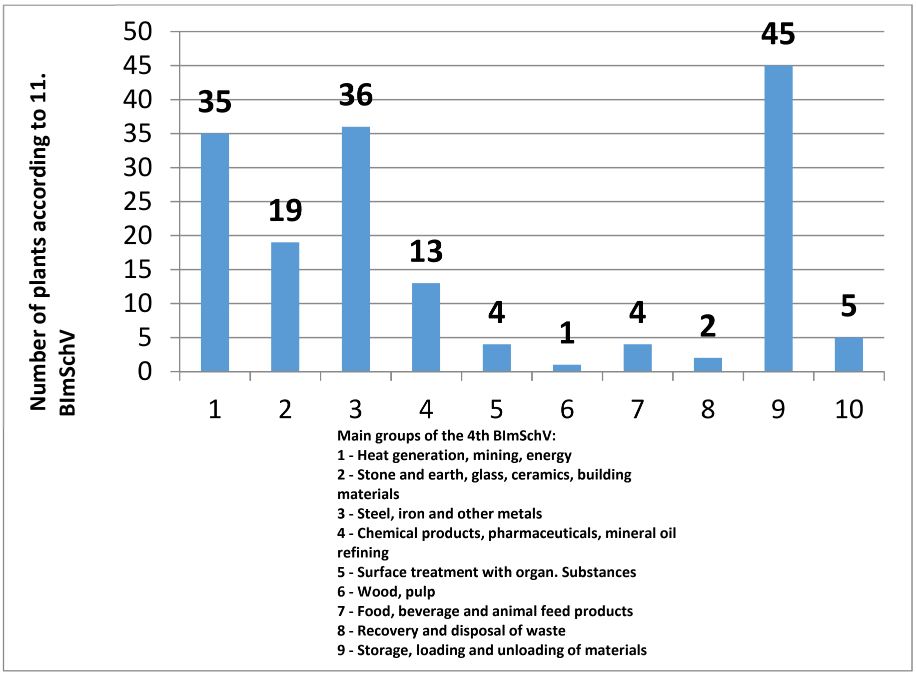


Figure 13: Number of industrial plants subdivided according to the main groups of the 4th BImSchV in the urban area of Duisburg

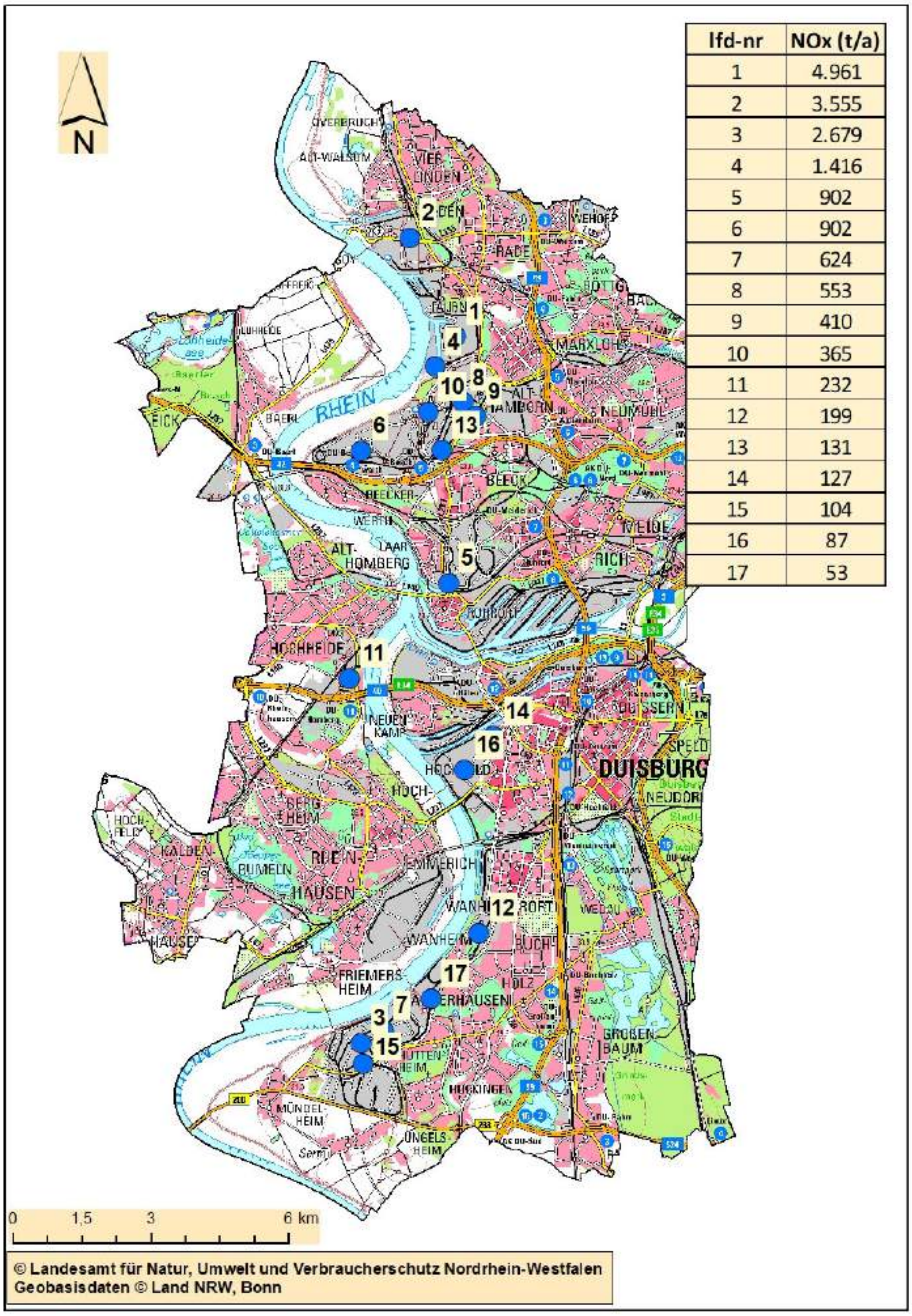
Table 16: NO_X-emissions of the main groups of the 4th BImSchV in the Duisburg urban area

Main group according to 4th BImSchV		NO_X-emissions	
		[t/a]	[%]
01	Heat generation, mining, energy	9 164,9	52.0
03	Steel, iron and other metals incl. further processing	8.230,8	46.7
	Other main groups	226.8	1.3
	Total	17 622.5	100.0

Table 17: The 17 largest nitrogen oxide emitters (operators) with industrial installations subject to authorization under the BImSchG in the Duisburg urban area.

Seq.-Nr.	Company	NO_X (t/a)
1	thyssenkrupp Steel Europe AG Werk Schwelgern	4 961
2	STEAG GmbH Heizkraftwerk Walsum	3 555
3	Hüttenwerke Krupp Mannesmann GmbH	2 679

4	Pruna Betreiber GmbH	1 416
5	thyssenkrupp Steel Europe AG Werk Ruhrort	902
6	thyssenkrupp Steel Europe AG Werk Beeckerwerth	902
7	Hüttenwerke Krupp Mannesmann GmbH KW Huckingen	624
8	thyssenkrupp Steel Europe AG Werk Bruckhausen	553
9	thyssenkrupp Steel Europe AG Werk Kraftwerk Hamborn	410
10	RWE Generation SE HKW Hamborn	365
11	Venator Germany GmbH	232
12	Stadtwerke Duisburg AG Heizkraftwerk III	199
13	thyssenkrupp Steel Europe AG Werk Hamborn	131
14	Stadtwerke Duisburg AG Heizkraftwerk I	127
15	thyssenkrupp Steel Europe AG Werk Hüttenheim	104
16	DK Recycling und Roheisen GmbH	87
17	Befesa Zinc Duisburg GmbH	53



lfd-nr	NOx (t/a)
1	4.961
2	3.555
3	2.679
4	1.416
5	902
6	902
7	624
8	553
9	410
10	365
11	232
12	199
13	131
14	127
15	104
16	87
17	53

Figure 14: The 17 largest nitrogen oxide emitters with industrial installations subject to authorization under the BImSchG in the Duisburg urban area.

5.1.2 *Plant structure in the Duisburg urban area (PM_{10})*

The dominant role of the metal industry (main group 3 of the 4th BImSchV) is even greater for PM_{10} than for NO_X (Table 18). Table 19 lists the 16 largest PM_{10} emitters (> 10 t/a).

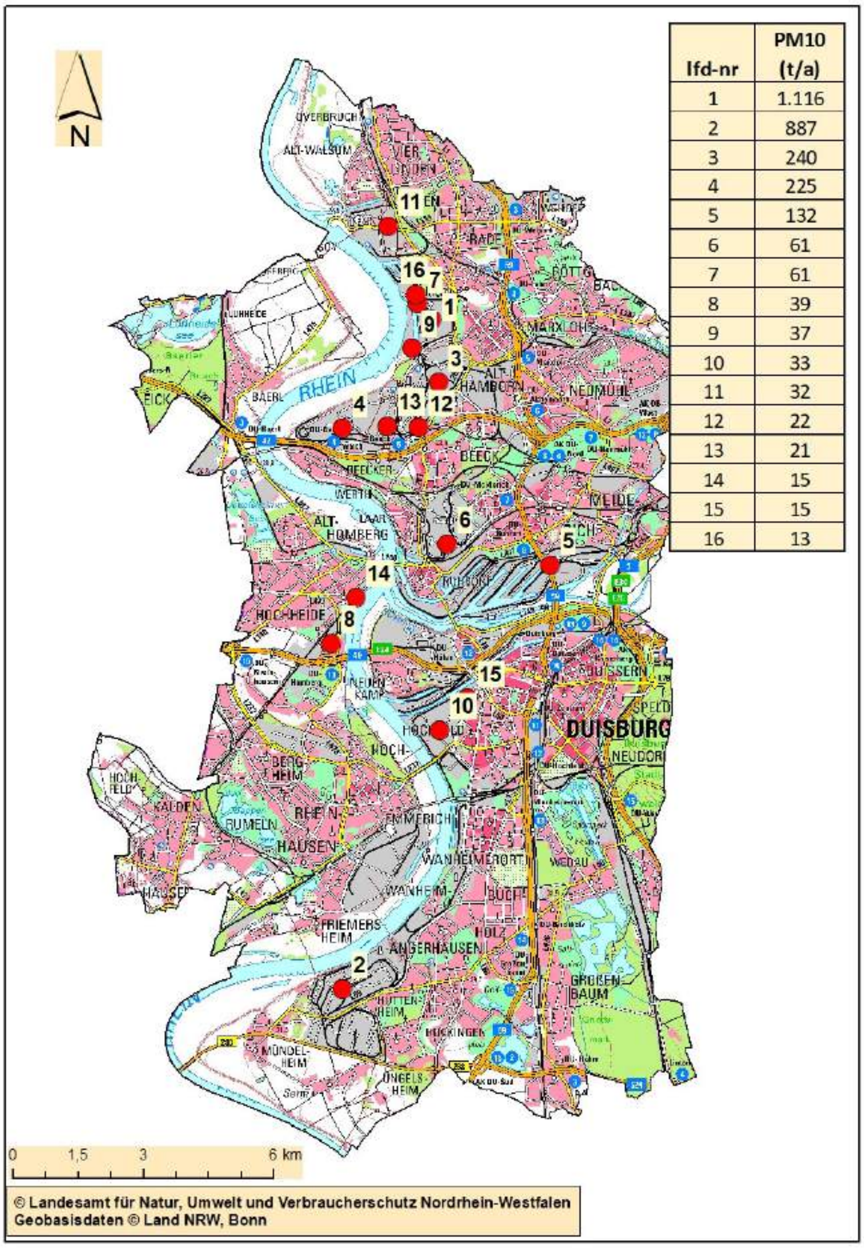
Table 18: PM_{10} emissions of the main groups of the 4th BImSchV in the urban area of Duisburg

Main group according to 4th BImSchV		PM_{10}-emissions	
		[t/a]	[%]
01	Heat generation, mining, energy	216.8	7.1
03	Steel, iron and other metals incl. further processing	2 287.3	75.3
	Other main groups	534.9	17.6
	Total	3 039.0	100.0

Table 19: The 16 largest PM10 emitters (operators) with industrial installations subject to authorization under the BImSchG in the Duisburg urban area.

Seq. Nr.	Company	PM_{10} (t/a)
1	thyssenkrupp Steel Europe AG Werk Schwelgern	1 116
2	Hüttenwerke Krupp Mannesmann GmbH	887
3	thyssenkrupp Steel Europe AG Werk Bruckhausen	240
4	thyssenkrupp Steel Europe AG Werk Beeckerwerth	225
5	neska GmbH Rhein-Ruhr Bulk Terminal	132
6	ArcelorMittal Ruhrort GmbH Werk Ruhrort	61
7	thyssenkrupp Steel Europe AG Hafenbetrieb	61
8	Venator Germany GmbH	39
9	Pruna Betreiber GmbH	37
10	DK Recycling und Roheisen GmbH	33
11	STEAG GmbH Heizkraftwerk Walsum	32
12	thyssenkrupp Steel Europe AG Werk Hamborn	22
13	ThyssenKrupp Mill Services & Systems GmbH	21
14	PMG Premium Mühlen GmbH & Co. KG	15
15	Stadtwerke Duisburg AG Heizkraftwerk I	15
16	Holcim WestZement GmbH Werk Schwelgern	13

Figure 15 shows the distribution of PM10 emitters (> 10 t/a) in the city area. The large Duisburg steel sites are also prominent here.



lfd-nr	PM10 (t/a)
1	1.116
2	887
3	240
4	225
5	132
6	61
7	61
8	39
9	37
10	33
11	32
12	22
13	21
14	15
15	15
16	13

Figure 15: The 16 largest PM_{10} emitters with industrial installations requiring a permit under the BImSchG in the Duisburg urban area.

5.1.3 Emitter group small and medium-sized combustion plants - plants not requiring a permit

In the area of installations not subject to licensing under immission control law, small combustion installations are to be considered as further emission sources for the urban area. For the year 2015, emissions in the entire urban area totaled approx. 236.3 t/a NO_X and 20.6 t/a PM_{10}.

5.1.4 Road traffic as an emitter group

NO_X emissions from road traffic in the city of Duisburg urban area amounted to 1,177 t/a for the year 2018.

5.1.5 Other emitter groups

Other emitter groups are agriculture, natural sources and other emitters. These emitter groups are not relevant for the pollution situation in the area of the inland port Duisburg.

5.2 Neuss/Düsseldorf Industry / Installations Requiring a Permit

Industrial facilities requiring permits are also present in Neuss/Düsseldorf. Here, too, it should be noted that most industrial emissions are emitted via high sources (smokestacks). When analysing the effect of emission sources on air pollution at waterways or other ground-level measurement locations, low nearby sources are particularly relevant.

5.2.1 Plant structure in the Neuss/Düsseldorf urban area (NO_X)

The urban area of Neuss/Düsseldorf is characterised by strong industrialisation. A total of 176 installations subject to licensing are registered here, of which 132 had to provide complete declarations in accordance with the 11th BImSchV with regard to the emissions caused. The distribution of these installations among the upper groups of the 4th BImSchV is shown in Figure **16**.

Table ***20*** (NO_X emissions of the main groups of the 4th BImSchV in the Neuss/Düsseldorf urban area) illustrates the dominant role of main groups 1 (heat generation, mining, energy) and 3 (steel, iron and other metals including processing, here: Aluminum) in the NO_X emissions. Figure 17 shows the distribution of NO_X emitters (> 20 t/a) in the city area. Table 21 lists the 18 largest nitrogen oxide emitters (operators) at Neuss/Düsseldorf.

Table 20: NO$_X$ emissions of the main groups of the 4th BImSchV in the urban area of Neuss/Düsseldorf

Main group according to 4th BImSchV		NO$_X$-Emissions [t/a]	NO$_X$-Emissions [%]
01	Heat generation, mining, energy	1 188.2	40.2
03	Steel, iron and other metals incl. further processing	949.2	32.1
	Other main groups	816.7	27.7
	Total	2 954.1	100.0

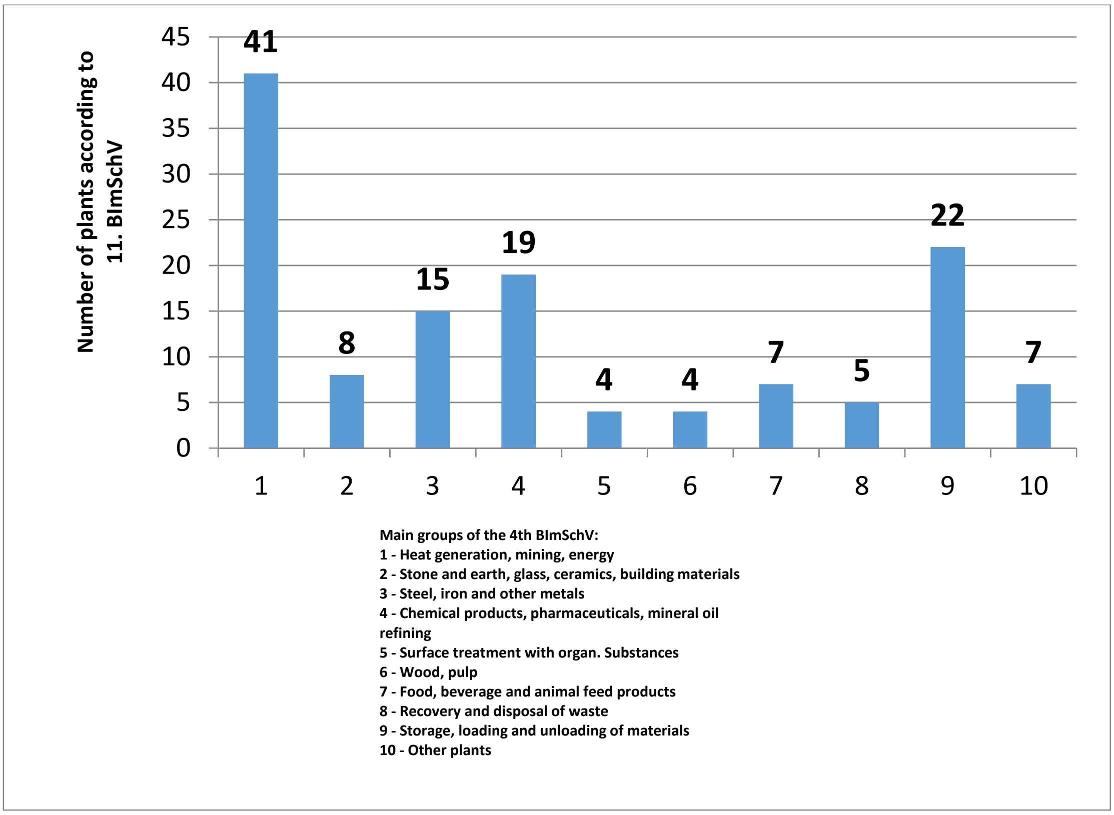
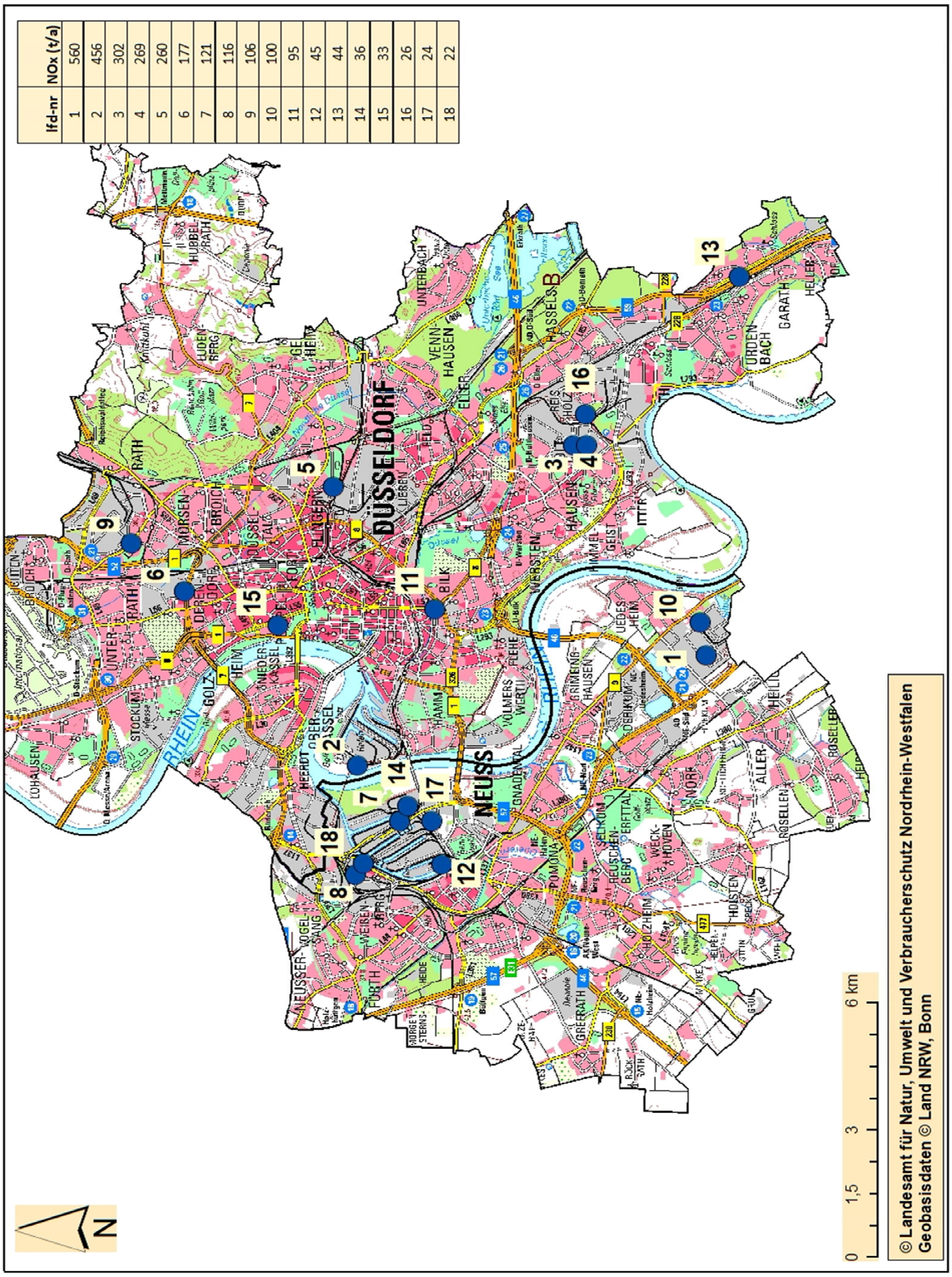


Figure 16: Number of industrial plants subdivided according to the main groups of the 4th BImSchV in the Neuss/Düsseldorf area



lfd-nr	NOx (t/a)
1	560
2	456
3	302
4	269
5	260
6	177
7	121
8	116
9	106
10	100
11	95
12	45
13	44
14	36
15	33
16	26
17	24
18	22

Figure 17: The 18 largest nitrogen oxide emitters (operators) with industrial installations subject to authorization under the BImSchG in the Neuss/Düsseldorf urban area.

Table 21: The 18 largest nitrogen oxide emitters (operators) with industrial installations subject to authorization under the BImSchG in the Neuss/Düsseldorf urban area.

Seq. Nr.	Company	NO_X (t/a)
1	Aluminium Norf GmbH	560
2	Stadtwerke Düsseldorf AG, Kraftwerk Lausward	456
3	Henkel AG & Co. KGaA	302
4	BASF Personal Care and Nutrition GmbH	269
5	Stadtwerke Düsseldorf AG, Müllverbrennungsanlage	260
6	Daimler AG Mercedes-Benz	177
7	Knauf Gips KG	121
8	FS Karton GmbH	116
9	Vallourec Deutschland GmbH	106
10	Hydro Aluminium Rolled Products GmbH	100
11	Julius Schulte Söhne GmbH & Co. KG	95
12	Protein- und Ölwerk Neuss GmbH & Co.KG	45
13	Stadtwerke Düsseldorf AG, Heizkraftwerk Garath	44
14	SCA Hygiene Products GmbH	36
15	ERGO Versicherungsgruppe AG	33
16	Vallourec Deutschland GmbH	26
17	KEMNA BAU Andreae GmbH & Co. KG	24
18	O. & L. Sels GmbH & Co. KG	22

5.2.2 Plant structure in the Neuss/Düsseldorf urban area (PM10)

Emissions in the urban area of Neuss/Düsseldorf are dominated by the plants of the aluminum industry and the plants of the food and animal feed industry (see Table 22).

Table 22: PM$_{10}$ emissions of the main groups of the 4th BImSchV in the urban area of Neuss/Düsseldorf

Main group according to 4th BImSchV		PM$_{10}$-emissions [t/a]	PM$_{10}$-emissions [%]
03	Stahl, Eisen und sonstige Metalle einschließlich Verarbeitung	85.9	46.5
07	Food, luxury food and animal feed	50.7	27.4
	Sonstige Obergruppen	48.3	26.1
	Total	184.9	100.0

Table 23 lists the 12 largest PM$_{10}$ emitters (> 4 t/a).

Table 23: The 12 largest PM10 emitters (operators) with industrial installations subject to authorization under the BImSchG in the Neuss/Düsseldorf urban area.

Seq. Nr.	Company	PM$_{10}$ (t/a)
1	Hydro Aluminum Rolled Products GmbH	60.4
2	PMG Premium Mühlen Gruppe GmbH & Co. KG	31.3
3	Daimler AG Mercedes-Benz	16.9
4	Henkel AG & Co. KGaA	14.0
5	Aluminium Norf GmbH	13.1
6	Deutsche Tiernahrung Cremer GmbH & Co.KG	7.1
7	KEMNA BAU Andreae GmbH & Co. KG	6.6
8	BASF Personal Care and Nutrition GmbH	5.6
9	Deutsche Tiernahrung Cremer GmbH & Co. KG	5.2
10	AGRAVIS Kraftfutterwerke Rhein-Main GmbH	5.0
11	RheinCargo GmbH & Co. KG	4.8
12	Knauf Gips KG	4.5

Figure 18 shows the distribution of PM10 emitters (> 4 t/a) over the urban area.

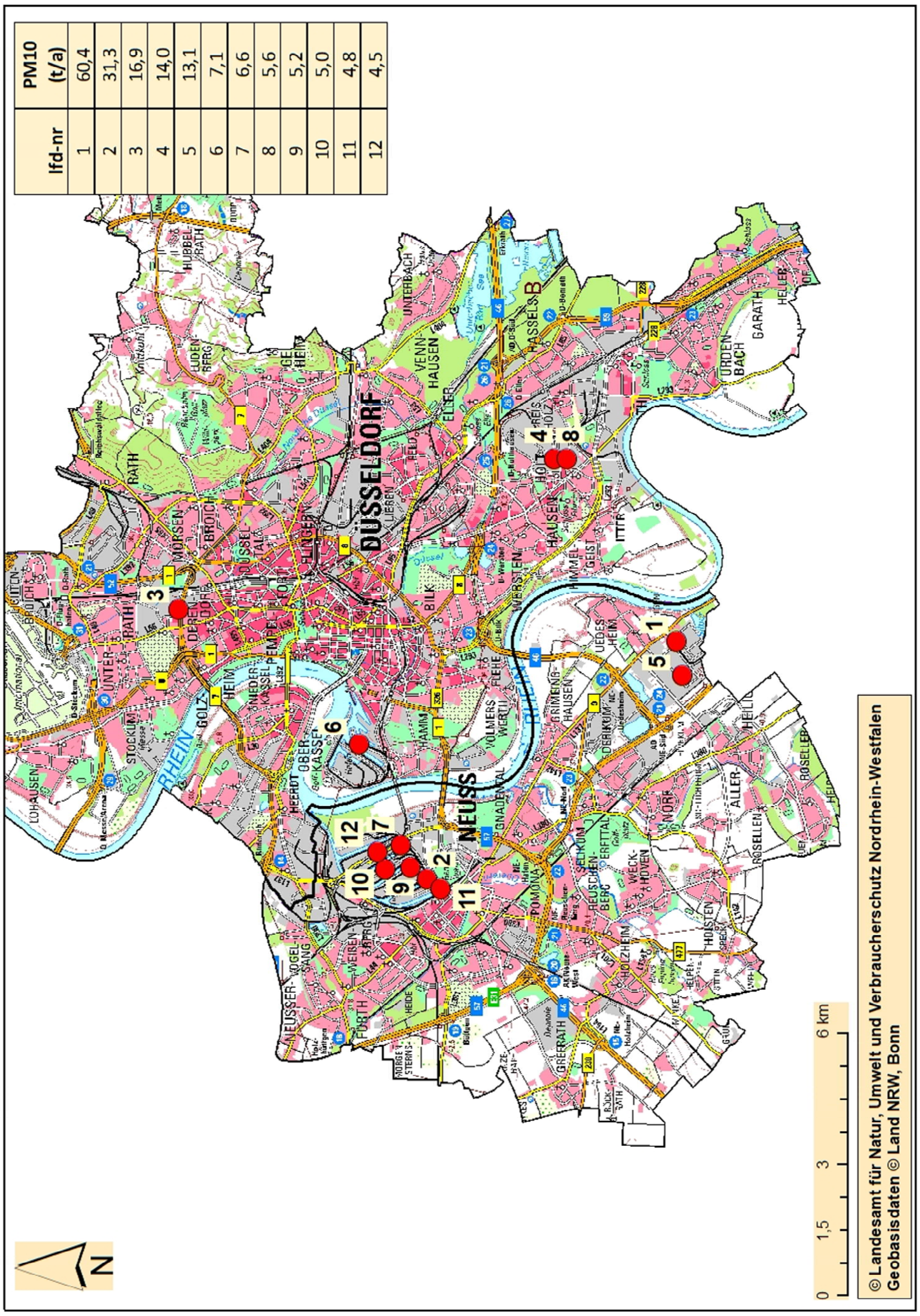


Figure 18: The 12 largest PM_{10} emitters (operators) with industrial installations subject to authorization under the BImSchG in the Neuss/Düsseldorf urban area.

5.2.3 Emitter group small and medium-sized combustion plants - plants not requiring a permit

In the case of installations that do not require a permit under the immission control law, small combustion plants are to be considered as further emission sources for the urban area. For the year 2015, emissions in the entire city area totaled around 477 t/a NO_X and 34.2 t/a PM_{10}.

5.2.4 Road traffic as an emitter group

NO_X emissions from road traffic in the Neuss urban area amounted to 513 t/a for 2018 and 2023 t/a for the Düsseldorf urban area.

5.2.5 Other emitter groups

Other emitter groups are agriculture, natural sources and other emitters. These emitter groups are not relevant for the pollution situation in the area of the inner harbour.

5.3 Overall analysis of the large-scale study area

For the immission modelling for the polluter root cause analyses, the emissions of all emitter groups were prepared in a larger study area (around 1,025 km²) containing both port areas (Duisburg and Neuss). This study area is marked as a rectangle in Figure 19. The emissions released in this study area therefore do not correspond exactly to the sum of the two city areas, as the accounting areas are not identical.

5.3.1 Industry

The emission cadastre for industrial facilities of NRW records the emissions of installations requiring a permit in NRW. These are based on the data of the emission declarations according to the 11th BImSchV(8) (Ordinance on Emission Declarations) of the operators of installations requiring a permit according to the Annex of the 4th BImSchV(7) (Ordinance on Installations Requiring a Permit). The current status represents the data collection from 2016, which is carried out in a 4-year rhythm and was adopted here for 2018) (Data of the LANUV 2021).

For polluter group industry, the emissions from installations requiring a permit are available as point sources. The NO_X emissions from industrial plants are shown together with the emissions from small combustion plants for the study area in Figure 19.

The industrial point sources show a clear concentration in and around the two port areas or urban areas of Duisburg and Neuss/Düsseldorf. In the entire study area, 19,511 t/a of NO_X emissions were released in 2018 by industrial facilities requiring a permit.

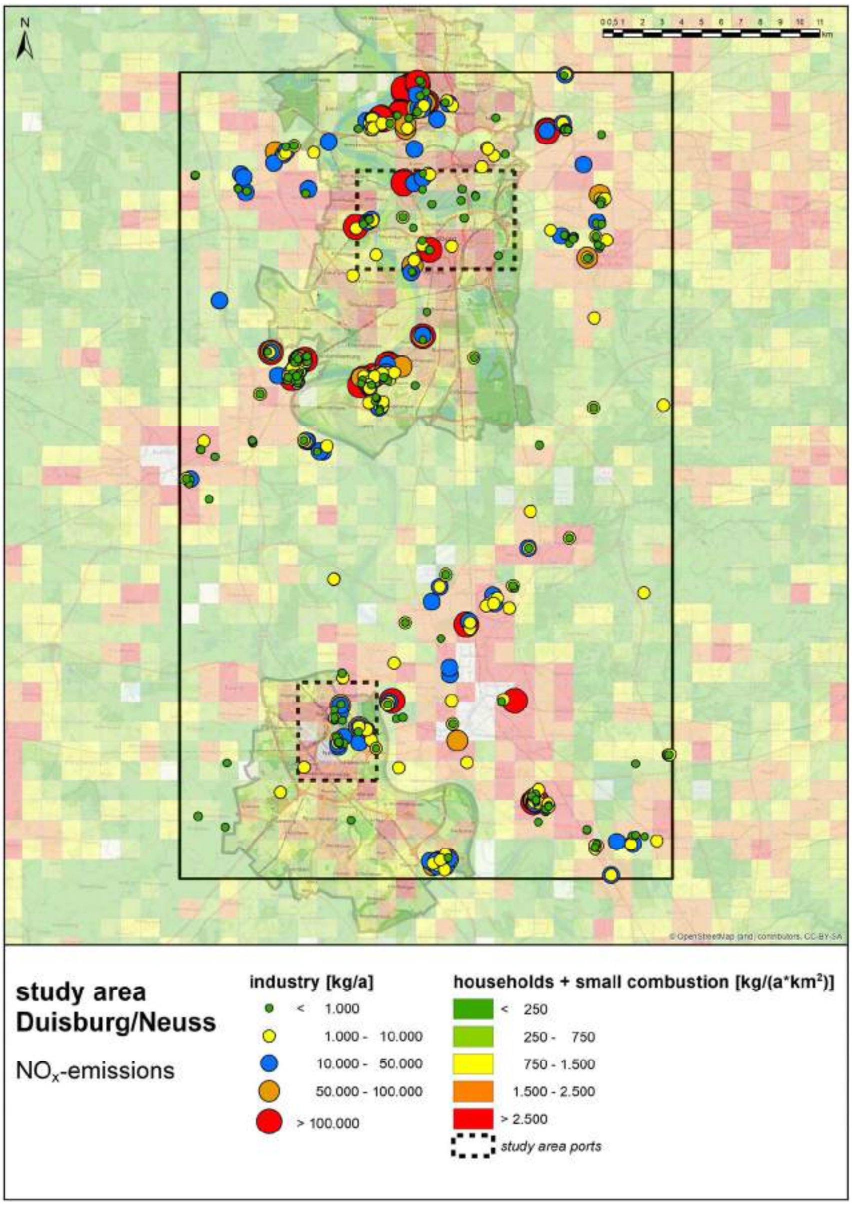


Figure 19: NO_X emitters from industry and small combustion plants (HuK) in the study area, analysis year 2018

The appendix also contains detailed illustrations of the emissions for the two port areas.

5.3.2 *Small combustion plants (HuK)*

Emissions from small combustion plants, not requiring a permit, are reported as a separate group of emitters. This group includes combustion plants in commercial enterprises, private households and other small consumers that do not fall under the scope of the 4th BImSchV.

The emission levels of this group of emitters refer to the survey year 2015. They are available as raster data in a 1km x 1km grid (HuK cadastre of LANUV 2021) and are also shown in Figure ***19*** together with the point sources of the industrial plants. Higher emission densities occur in the populated areas; the total NO_X emissions from small combustion plants in the study area are 1,151 t NO_X/a.

5.3.3 *Transport sector*

The emission inventory of the State of NRW contains the following relevant emitter groups for the transport sector:

- Road traffic
- Air traffic
- Rail transport
- Off-road

The emissions from road traffic are currently available for the relevant public road network for the year 2017[(11)]. Data on traffic loads are calculated from traffic counts and emission factors that describe the exhaust behaviour of the vehicle fleet depending on vehicle-specific influencing factors (drive type, exhaust after-treatment concept, weight class, etc.). The NO_X emissions of road traffic in the overall study area are 4,971 t/a. Figure 20 shows the emissions from road traffic as line sources. The highest loads are shown for the motorways that cross the area.

For air traffic, ground-level emissions in the LTO cycle were determined for each airport for the NRW emission inventory (reference year 2013). The study area includes Düsseldorf Airport, which dominates the emissions from air traffic, as well as several small landing sites, e.g. for helicopters at hospitals. The NO_X emissions from air traffic in the entire study area amount to 913 t/a. Figure 20 shows the emissions of air traffic in a 1km x 1km grid. The area in the direct vicinity of the airport with the highest emission densities and the areas swept by aircraft on approach and departure can be seen.

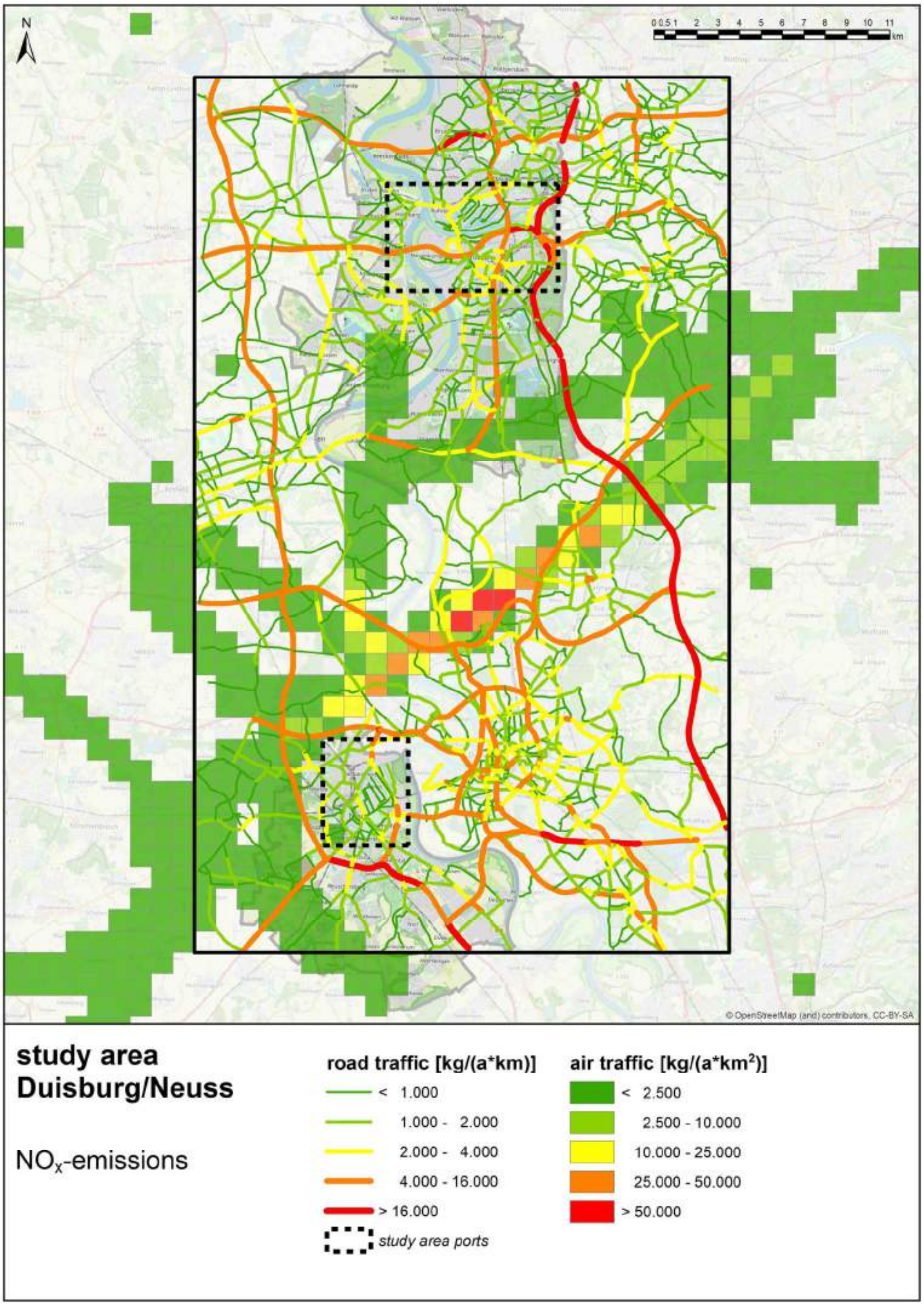


Figure 20: NO_X emissions from road traffic and air traffic in the study area, analysis year 2018

The state of North Rhine-Westphalia also maintains an emission cadastre for emissions from rail traffic on the DB AG rail network (12), currently for the year 2018. 337 t/a of NO_X emissions were released by rail traffic in the study area. These are emissions from diesel-powered train traffic, including shunting operations.

Figure 21 illustrates the emissions from rail traffic on the DB AG rail network and shows the highest emission levels along the east-west railway line running in the south. In addition, the emissions from the port railway are also shown in Figure 21, which are not included in the DB AG data and its determination is explained in the following chapter on the special surveys in the port areas.

Emissions from off-road transport include emissions from mobile equipment and machinery in the following categories:

- Construction machinery
- Forestry
- Agriculture
- Gardening and hobby
- Industry
- Military

The emissions of the off-road sector are available from the emission inventory of the LANUV NRW in a 1km x 1km grid and are also shown in Figure 21. Higher emission densities occur mainly in some areas of the two urban areas. The NO_X emissions from off-road traffic in the study area are in total 401 t/a.

Detailed illustrations of the emissions from the transport sector in the two port areas can be found in the appendix.

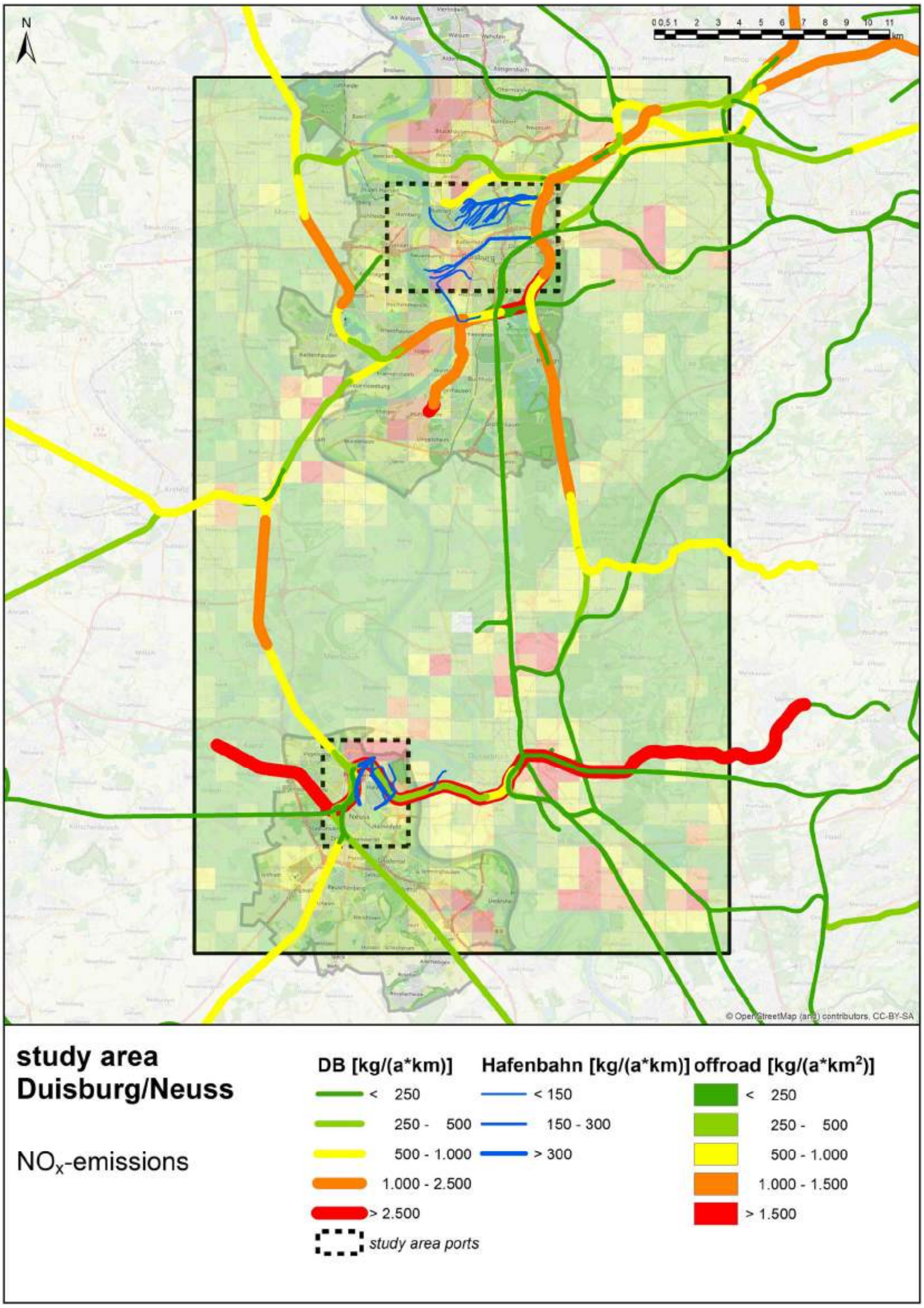


Figure 21: Emissions from rail traffic and off-road in the study area, analysis year 2018

6. Special surveys for CLINSH on traffic in the port areas

Since the emissions of the two port areas in particular were to be determined in detail, some special surveys were carried out for these areas. On the one hand, the traffic loads within the port areas were obtained, in order to determine the emissions from road traffic there at line source level. Furthermore, research was carried out on the port railways and industrial trucks and their emission behaviour. In addition, emissions from vehicle loading in Neuss were estimated.

The data basis and results of these detailed investigations are explained below. In addition, detailed representations of the emissions determined for the two port areas can be found in the appendix.

6.1 Traffic emissions in the Duisburg port area

6.1.1 Road traffic in the Duisburg port area

The city of Duisburg carried out a traffic count in the port area of Duisburg for the CLINSH project[13]. Counting data from 24-hour counts were provided for the following seven counting points in the port area (differentiated according to the vehicle types motorbike, car, delivery van, truck without trailer, truck with trailer, bus, bicycle):

- Zum Container Terminal
- Schlickstraße
- Schlickstraße / Bürgermeister-Pütz-Straße
- Am Nordhafen / Vohwinkelstraße / Im Freihafen
- Alte Ruhrorter Straße
- Vinckeweg / August-Hirsch-Straße
- Mercatorinsel

The annual average traffic volumes derived from this traffic census are shown in Figure 22. Within the actual port of Duisburg, the motor vehicle loads on the individual stretches are a maximum of 1,400 vehicles/24h, the proportion of heavy goods vehicles (HGVs > 3.5 t permissible total weight) is in some cases very high (up to 70%), e.g. in the area of the container terminals.

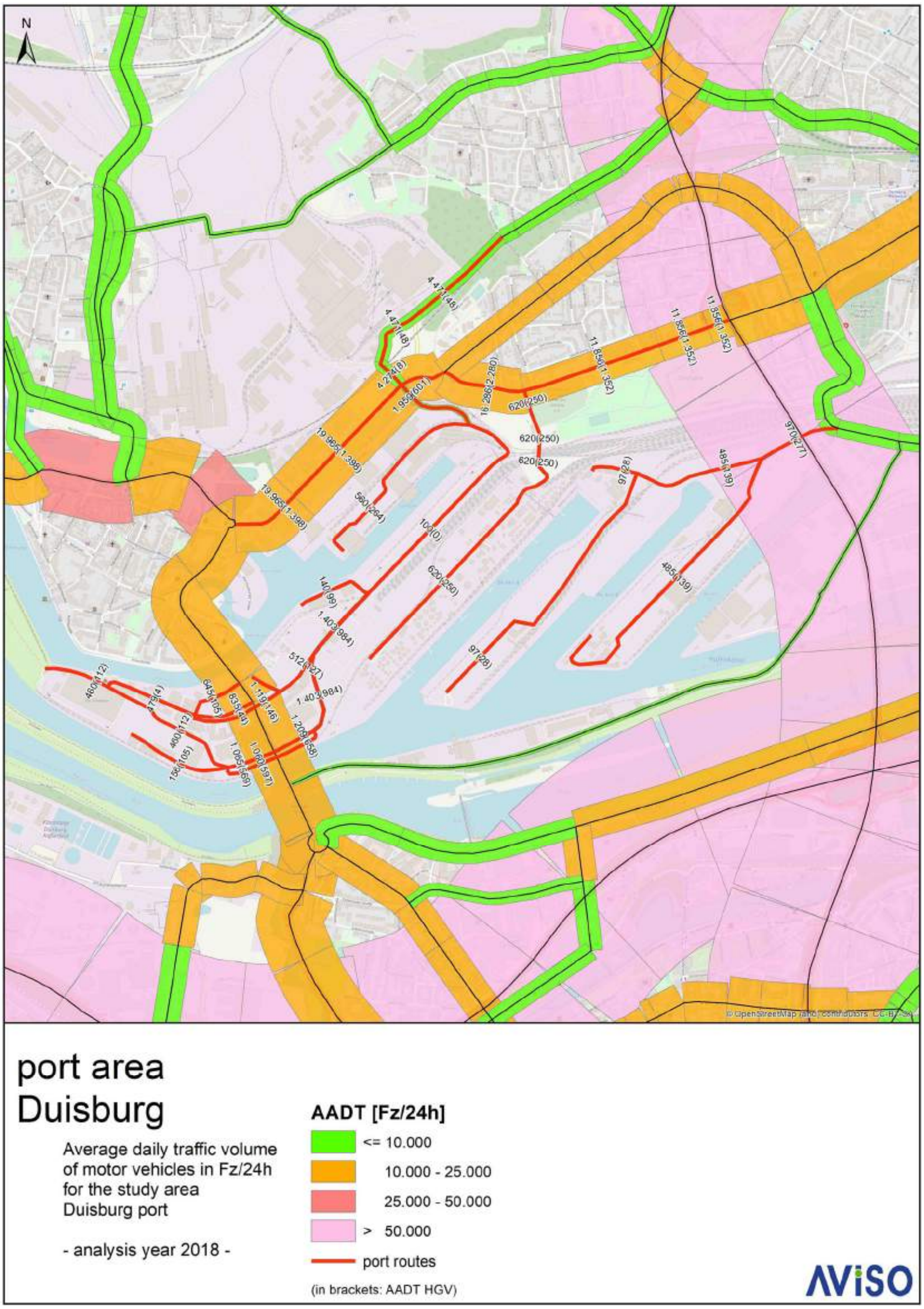


Figure 22: Motor vehicle traffic volumes in the port area for the analysis year 2018 (AADT=daily traffic volume, vehicles per day).

To determine the emissions of road traffic on the basis of the collected traffic data, the same emission factors were used as for the calculations for the Clean Air Plan Duisburg for the analysis year 2018[14]. These are based on the data of the Manual for Emission Factors of Road Transport (HBEFA 2021)[10], whereby the regional fleet composition (differentiated by type of drive, Euro standard stage, weight class, etc.) was taken into account for the passenger cars and light commercial vehicles. The calculation was carried out using HBEFA version 3.3. A nationally averaged fleet composition was assumed for the heavy commercial vehicles. The annual emissions for the pollutants NO_X and NO_2 were determined for each line source.

The results of the emission calculations for the Duisburg port area are shown in Figure 23 for NO_X. It is clear that the emission densities on the roads in the port area are much lower than on the surrounding public road network, which has significantly higher traffic loads.

The annual mileage and total emissions for the analysis year 2018 are differentiated by vehicle category for the port area in Table 24. The emissions from the directly adjacent public roads are also included in the balance sheet. If only the stretches of road directly in the port area are considered, the annual emissions of NO_X are only 3.15 t/a.

Table 24: Annual mileage, NO_X and NO_2 emissions in 2018 for the port area of Duisburg, differentiated by vehicle category.

Road traffic in the port of Duisburg		Passenger cars	Light commercial vehicles	Buses	Motorbikes	Heavy commercial vehicles	Road trains and articulated lorries	Total
Mileage	**Mio.FZkm/a**	**814,44**	**61,11**	**4,19**	**11,71**	**28,06**	**53,96**	**973,48**
		83,7%	*6,3%*	*0,4%*	*1,2%*	*2,9%*	*5,5%*	*100,0%*
NO_X	**t/a**	**230,78**	**37,53**	**19,19**	**1,56**	**34,85**	**63,93**	**387,84**
		59,5%	*9,7%*	*4,9%*	*0,4%*	*9,0%*	*16,5%*	*100,0%*
NO_2	**t/a**	**65,46**	**12,24**	**4,15**	**0,08**	**4,23**	**9,10**	**95,26**
		68,7%	*12,8%*	*4,4%*	*0,1%*	*4,4%*	*9,6%*	*100,0%*

The calculation was carried out using HBEFA version 3.3.

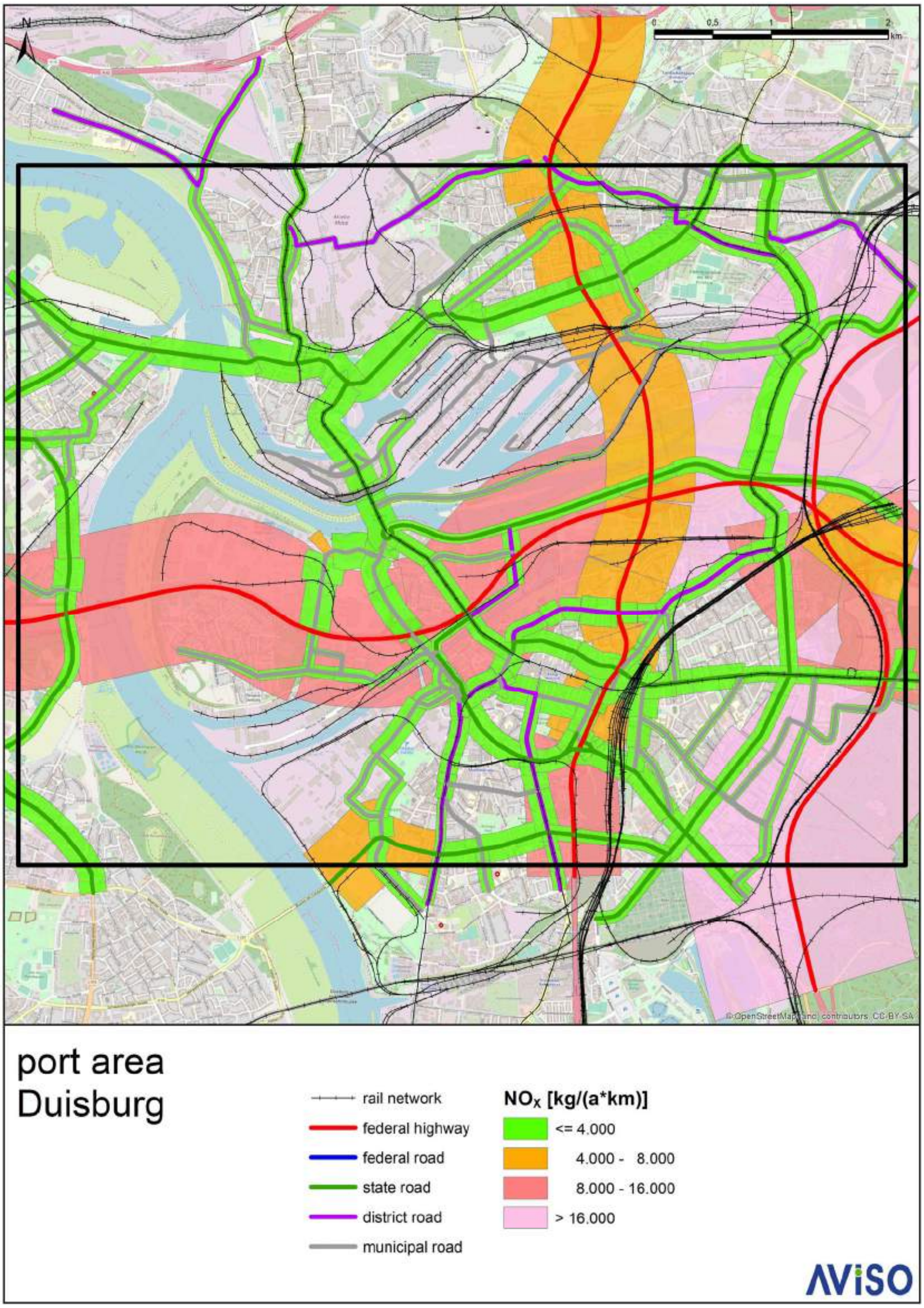


Figure 23: Annual NO_X emissions from road traffic in the port area of Duisburg, analysis year 2018

6.1.2 Rail traffic / port railway in the port area of Duisburg

The port operator ***duisport*** provided data on the number of movements of the port railway, to represent the rail traffic within the port area (LANUV 2019a [(15)]) (see Appendix A). These range from 8 journeys/day to 40 journeys/day depending on the track section in the port.

Data on the locomotives used were also provided (LANUV 2019b) [(16)] (see Appendix B). In addition, typical emission characteristics had to be assigned to the locomotives used, as no concrete information on the real emission behaviour in operation was available for the individual locomotives. For this purpose, information from DB AG on typical emission characteristics and consumption values and supplementary data from the Swiss non-road database could be used.

The emission factors for locomotives for shunting operations from the DB AG data (LANUV 2019c) [(17)] are listed in Table 25. In addition, emission factors for a typical diesel-powered shunting locomotive from the non-road database of the Swiss Federal Office for the Environment (BAFU 2021)[(18)] are listed in Table 26.

Table 25: DB AG emission factors for series 202 and 203 from the DB AG database (17) and fuel consumption as average values across the entire DB fleet (in the range of the respective shunting locomotive classes).

model series	NOx [g/kg]	Fuel consumption [l/h]
BR 202	26.754	
BR 203	32.42	
small shunting locomotive (e.g. DB BR 363)		3-6
heavy shunting locomotive (e.g. DB BR 261)		10-20

Table 26: Emission factors [kg/h] for diesel-powered shunting locomotives (>560 kW, rail_D_EU3a) from non-road database (BAFU 2021) (18)

model series	NOx [kg/h]	Fuel consumption [kg/h]
shunting locomotive (>560 kW, Schiene_D_EU3a)	0.6911	29.3974

In addition, data on specific NO_X emissions related to fuel consumption were available from the technical data sheet of two different locomotives. These are compared in
Table ***27*** to the emission factors of DB AG [(17)] and the data from the non-road database of the BAFU[(18)]. The emission factors from DB AG and BAFU are in the range of 23.5 to 32.4 g NO_X/kg fuel, those from the sales data sheet at approx. 28 g NO_X/kg fuel and thus within this range.

Table 27: Comparison of emission factors [g/kg fuel] from the different sources

Pollutant	Source	Name	Emissions [g/kg]
NO_X	sales data sheet	12V4000R43L	28.571
		8V4000R43L	29.126
	DB AG	BR 202	26.754
		BR 203	32.420
	BAFU	shunting locomotive (>560 kW, Schiene_D_EU3a)	23.509

For the emission calculation, a fuel consumption of 20 l diesel per operating hour (corresponds to a consumption of approx. 16.6 kg/h) and an average emission factor of 29.587 g/kg were taken from the DB AG data. Furthermore, it is assumed that the average speed is approx. 20 km/h. This results in a mileage-related emission factor for NO_X of **24.6 g/km**. As a result, 4.95 t of NO_X emissions could be determined on this basis for the operation of the Duisburg port railway for the year 2018.

6.1.3 Industrial trucks in the Duisburg port area

In addition to the port railway, diesel-powered industrial trucks are also used in the Duisburg port area and their emissions were additionally determined. For the port of Duisburg, it was assumed that 10 diesel-powered reach stackers with an output of approx. 200-300 kW are used (information from ***duisport***).

To estimate the emissions caused by the industrial trucks in the port of Duisburg, the emission factors for pneumatic/mobile cranes in the 130-300 kW power class from the non-road database of the Swiss Federal Office for the Environment (BAFU 2021) were used. Overall, emissions of 3.82 t/a NO_X were determined for the industrial trucks in Duisburg.

6.2 Traffic emissions in the Neuss/Düsseldorf port area

6.2.1 Road traffic in the Neuss/Düsseldorf port area

For the Neuss port area, Rheincargo conducted a traffic census for the CLINSH project and provided the data [(19)]. These are the results of traffic counts with side radar devices at a total of 16 measurement cross-sections in the port area on the following roads:

- Industriestrasse
- Hansastrasse
- Danziger Strasse
- Duisburger Strasse
- Königsberger Strasse
- Tilsiter Strasse
- Floßhafenstraße

The data is differentiated according to cars, lorries and road trains and annual average traffic volumes were derived from it, which are shown in Figure 24 for the port area and the immediate surroundings. The maximum traffic loads are somewhat higher than in the Port of Duisburg, here at a maximum of 3,300 vehicles per 24 hours. The share of heavy traffic is in the range of 20% to 40%.

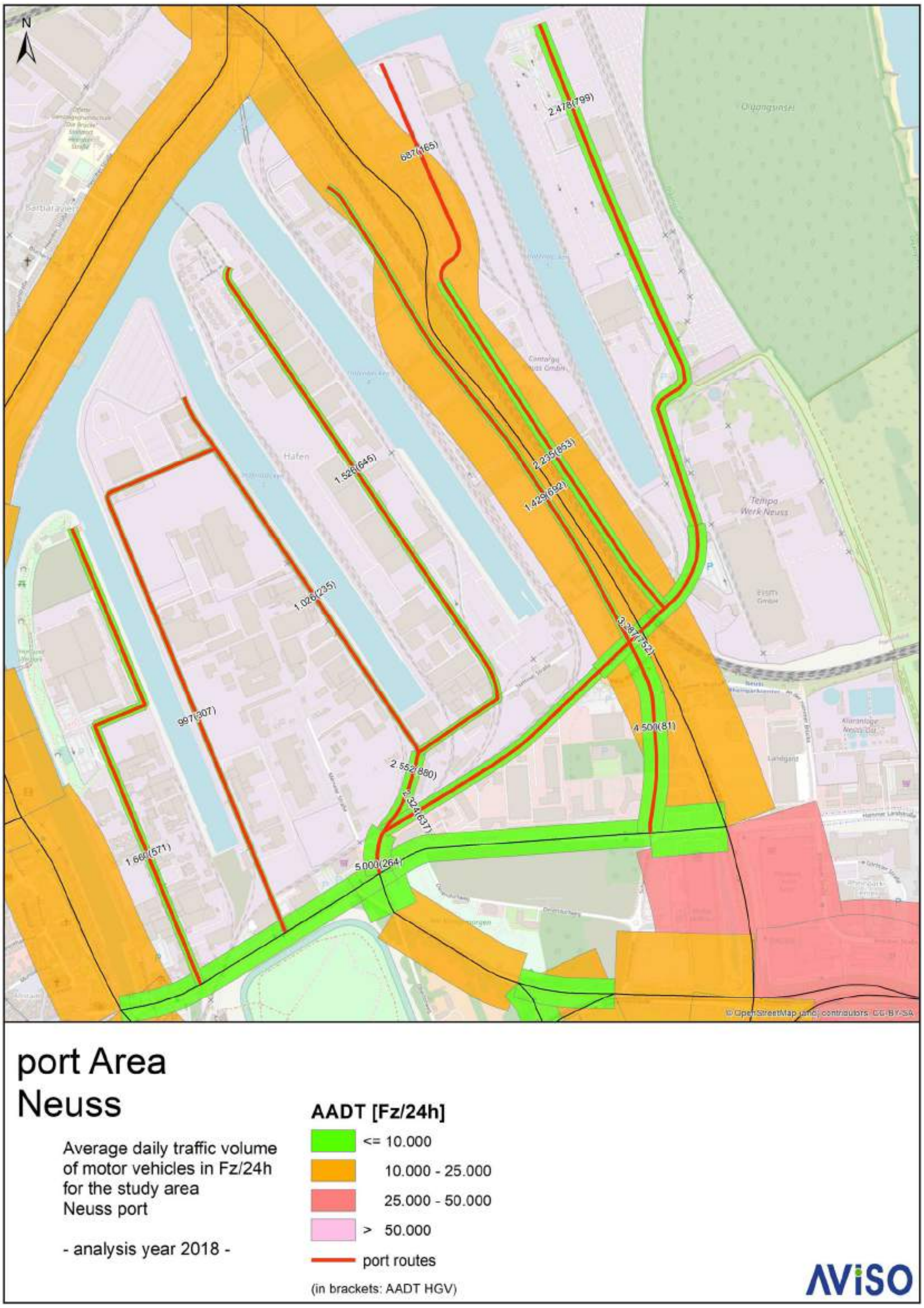


Figure 24: Motor vehicle traffic volumes in the port area for the analysis year 2018 (AADT=daily traffic volume, vehicles per day)

The same emission factors were used to determine the emissions from road traffic in the port of Neuss as for the calculations for the Neuss Clean Air Plan for the analysis year 2018 [20]. These are based on the data of the Manual for Emission Factors of Road Transport (HBEFA 2021)[10], whereby the regional fleet composition for Neuss was taken into account for the passenger cars and light commercial vehicles. The calculation was carried out using HBEFA version 3.3. A nationally averaged fleet composition was assumed for the heavy commercial vehicles. The annual emissions for the pollutants NO_X and NO_2 were determined for each line source.

The results of the emission calculations for the port area are shown in Figure 25. Similar to Duisburg, the NO_X emission densities on the roads in the port area are lower than those on the surrounding public road network, where traffic loads are significantly higher.

The annual mileage and total emissions are differentiated by vehicle category for the port area in Table 28 for the analysis year 2018. The emissions from the directly adjacent public roads are also included in the balance sheet. If only the stretches of road directly in the port area are considered, the annual emissions of NO_X are only 9.13 t/a.

Table 28: Annual mileage, NO_X and NO_2 emissions for the port area of Neuss, differentiated by vehicle category, analysis year 2018.

Road traffic in the port of Neuss		Passenger cars	Light commercial vehicles	Buses	Motor-bikes	Heavy commercial vehicles	Total
mileage	Mio.FZkm/a	209,62	17,17	2,02	3,06	13,96	245,82
		85,3%	*7,0%*	*0,8%*	*1,2%*	*5,7%*	*100,0%*
NO_X	t/a	64,92	8,40	7,06	0,30	25,18	105,87
		61,3%	*7,9%*	*6,7%*	*0,3%*	*23,8%*	*100,0%*
NO_2	t/a	16,06	2,52	1,81	0,02	3,09	23,49
		68,4%	*10,7%*	*7,7%*	*0,1%*	*13,2%*	*100,0%*

The calculation was carried out using HBEFA version 3.3.

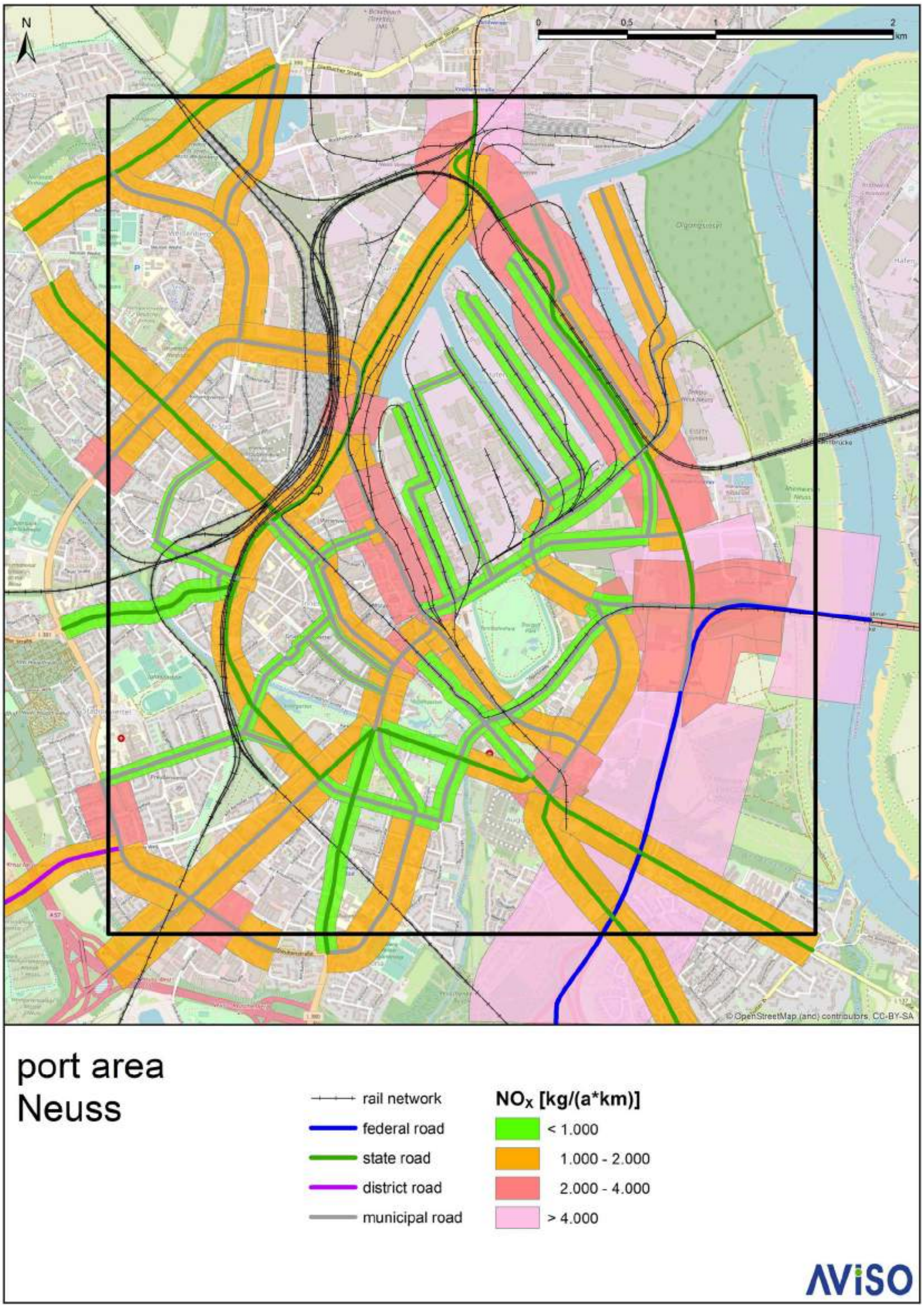


Figure 25: Annual NO_X emissions from road traffic in the Neuss port area, analysis year 2018

6.2.2 Rail traffic/port railway in the Neuss/Düsseldorf port area

For rail traffic within the port area, data on the number of movements was provided by **Rheincargo** (LANUV 2019d)[21] (see Appendix C). This results in up to 39 journeys/day for the port railway depending on the route section. With regard to the emission factors used for the emission calculation, the same data basis was used as for Duisburg, i.e. a mileage-related emission factor for NO_X of 24,6 g/km was applied. As a result, 2,478 t of NO_X emissions could be determined for the operation of the Neuss port railway for 2018 on this basis.

6.2.3 Industrial trucks in the port area of Neuss/Düsseldorf

Rheincargo also determined data on the number of industrial trucks used in the port of Neuss. The actual number of vehicles in use in the port of Neuss is not known, but it is assumed that an annual average of 10-15 vehicles are in use **(Rheincargo)**. The reach stackers used as industrial trucks are diesel-powered and usually have an output of approx. 200-300 kW.

In order to estimate the emissions caused by the industrial trucks in the port of Neuss, the emission factors for pneumatic/mobile cranes in the 130-300 kW performance class from the non-road database of the Swiss Federal Office for the Environment (BAFU 2021)[18] were used in the same way as for the port of Duisburg.

In total, NO_X emissions of 3.0 t/a were determined for the industrial trucks in Neuss. These were placed as area sources on the areas of the container terminals.

6.2.4 Car loading in the Neuss/Düsseldorf port area

Emissions from the Neuss car terminal were estimated as an additional source of exhaust emissions. According to the port operator **Rheincargo**, 27,616 vehicles were unloaded at this terminal in 2018. These travel independently (self-propelled) over a distance of 200m on average. It is predominantly about (approx. 60-70%) small cars of the Ford brand (Fiesta) and assumed that all unloaded vehicles are in cold start. The diesel share was set at 32.3%, analogous to the diesel share in new registrations in Germany, and it was assumed that these are vehicles that comply with the Euro 6 standard.

The emission factor for Euro 6 passenger cars was determined on the basis of data from the Handbook for Emission Factors of Road Transport (HBEFA 2021)[10], as in the calculations for road traffic emissions, whereby a traffic situation with low driving speeds was taken as a basis here. The calculation was carried out using HBEFA version 3.3. As a result, NO_X emissions of 1.98 kg/a were determined for car loading. The emissions were considered as a line source in the total emissions of the port area. A measurable influence on the air quality in the port is not to be expected.

7. Summary of emissions in the study area and the port areas

Finally, the emissions of all emitter groups determined and described in the previous chapters are listed again in summary for the whole study area and subsequently for the two port areas.

7.1 Study area

The comprehensive study area of Neuss/Düsseldorf/Duisburg covers an area of 1,025 km².

The NO_X emissions of all emitter groups in the study area are summarized in the following Table 29. The largest share of NO_X emissions (62%) is caused by industrial installations requiring a permit. These are predominantly released via stacks at greater heights and not close to the ground.

Road traffic accounts for 16% and shipping for 11%. In contrast, the other emitter groups of air traffic, off-road and small combustion plants only contribute a maximum of 4% to the total NO_X emissions.

Table 29: Annual NO_X emissions in the whole study area, analysis year 2018

Sector	Whole study area	
	NO_X-emissions (t/a)	percentage
Ship traffic	3,252	11%
Road traffic	4,971	16%
Industry	19,511	64%
Rail traffic	330	1%
Flight traffic	913	3%
Offroad	408	1%
Small combustion	1,151	4%
Total	30,536	

7.2 Port areas Duisburg and Neuss/Düsseldorf

If only the two port areas are considered in each case, then basically similar ratios can be seen (Table 30). The emissions of the emitter group industry have the largest share of NO_X emissions with 59%, resp. 55% in Neuss and Duisburg. However, it should be noted that in absolute values the NO_X emissions from industry in the port area of Duisburg are higher by a factor of three than in the port area of Neuss.

The NO_X emissions caused by shipping traffic in the port area (excluding the Rhine) are 10.4% of the total emissions in Neuss and 6.5% in Duisburg.

Table 30: Annual NO_X and NO_2 emissions for the port area, differentiated by emitter category, analysis year 2018

Sector	Port area Neuss, 2018		Port area Duisburg, 2018	
	NO_X t/a	percentage	NO_X t/a	percentage
Tanker vessels, at berth	4.27	0.7%	11.64	0.5%
Cargo vessels at berth	4.06	0.6%	3.88	0.2%
Car loading station Neuss	0.00	0.0%	-	-
Moving ships in the port	18.68	2.9%	25.11	1.1%
Locking operations	-	-	26.23	1.2%
Lock traffic	-	-	16.20	0.7%
Industrial trucks	3.00	0.5%	3.82	0.2%
Port rail traffic	2.48	0.4%	4.95	0.2%
Rail traffic	38.32	6.0%	16.58	0.8%
Road traffic	105.87	16.5%	387.84	17.6%
Moving ships on the Rhine	-	-	356.83	16.2%
Industry	403.97	62.8%	1 276.28	58.1%
Flight traffic	0.02	0.0%	-	-
Offroad	13.78	2.1%	19.33	0.9%
Small combustion	48.45	7.5%	49.79	2.3%
Total	642.90		2 198.5	

Boundary of the port areas Duisburg and Neuss : See Fig. 5 and Fig 6, inner boxes

8. Outlook

With the new data collected within the framework of CLINSH and the newly developed methods for calculating emissions from ships underway and in port, it has become possible to record and assess the influence of shipping and port operations on the air quality in much more detail in future.

The LANUV NRW is planning to apply these new methods in the upcoming update of the emission cadastre for inland vessels.

9. Acknowledgement

We would like to thank all colleagues at the LANUV who helped us to prepare this report. In particular, we would like to thank Gerhard Kobs and Sabine Turhan for preparing many tables and figures from the emission inventories and Petra Jeworrek-Mayer for proofreading the English manuscript.

The port operators **Rheincargo** (Neuss/Düsseldorf) and ***duisport*** (Duisburg) made the investigations for CLINSH in the port areas possible and supported us with advice and lots of data.

Very special thanks to Jan Eckel, Managing Director of the port operator Rheincargo (Neuss port area), Thomas Griebe and Peter Heise from the City of Duisburg (Duisburg port area) for carrying out the additional traffic counts in the port areas and Alexander Garbar, who provided us with a lot of data on ships in the Port of Duisburg.

10. Literature

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- "Harbour Monitoring Part E: Determination of NO_X emission rates of passing vessels from onshore measurements, comparison to onboard observations and application for emission calculations"
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11. List of Tables

12. List of Figures

Figure 26: Cargo ship at berth in the port of Neuss

13. Appendix

Appendix Detailed representations of emissions in the port areas of Duisburg and Neuss/Düsseldorf.

Background maps: Digital orthophotos (Source: OpenGeodata.NRW)

Appendix A: Port of Duisburg railway (journeys per day)

Appendix B: Locomotives used Port of Duisburg

Appendix C: Port railway Neuss (trips per day)

Appendix D: Locomotives used in the Neuss port area

Appendix Detailed representations of emissions in the port areas of Duisburg and Neuss/Düsseldorf

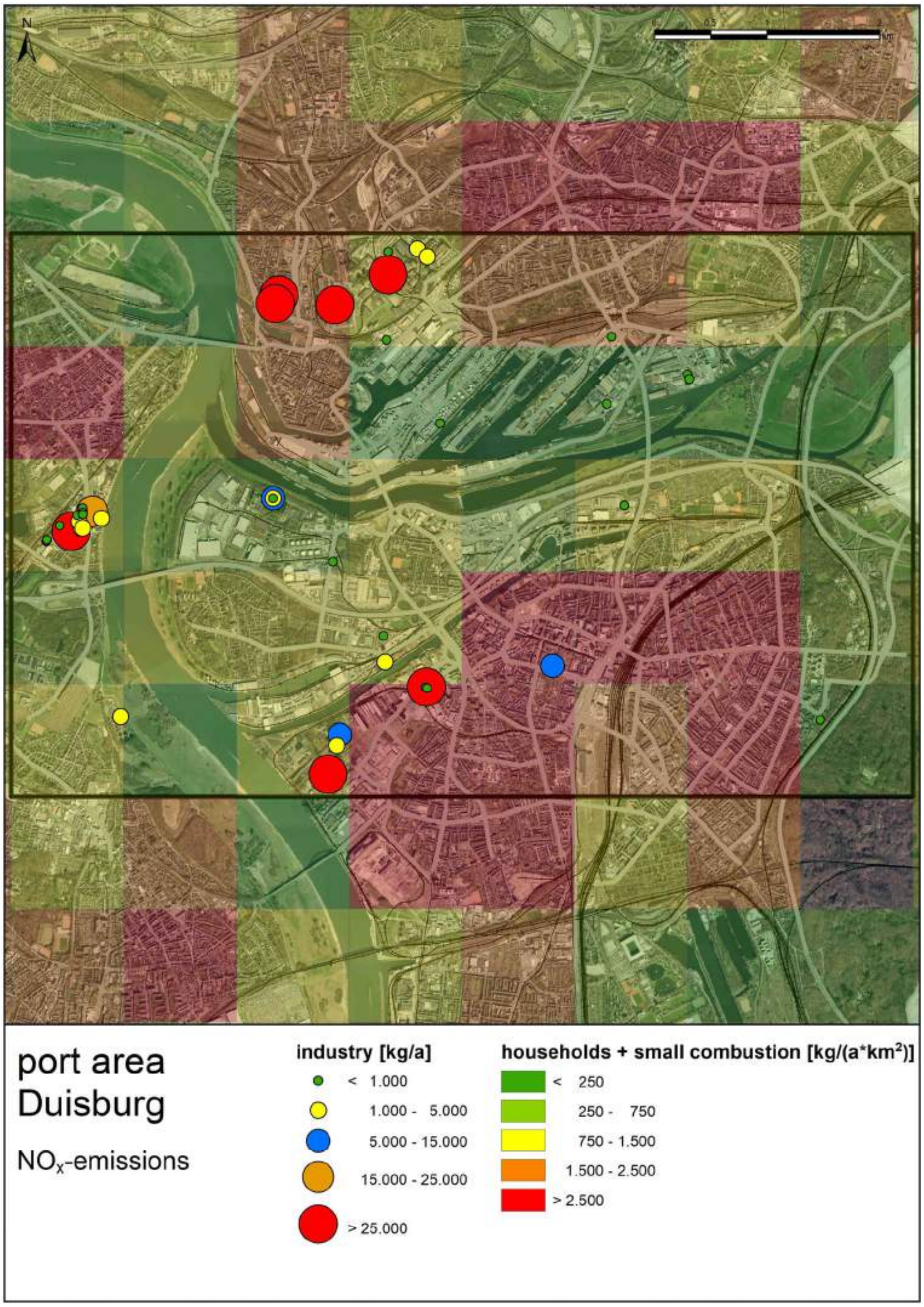

Figure 27: Annual NO_X-emissions from industrial sources, small combustion plants and domestic furnaces in the Duisburg port area, analysis year 2018

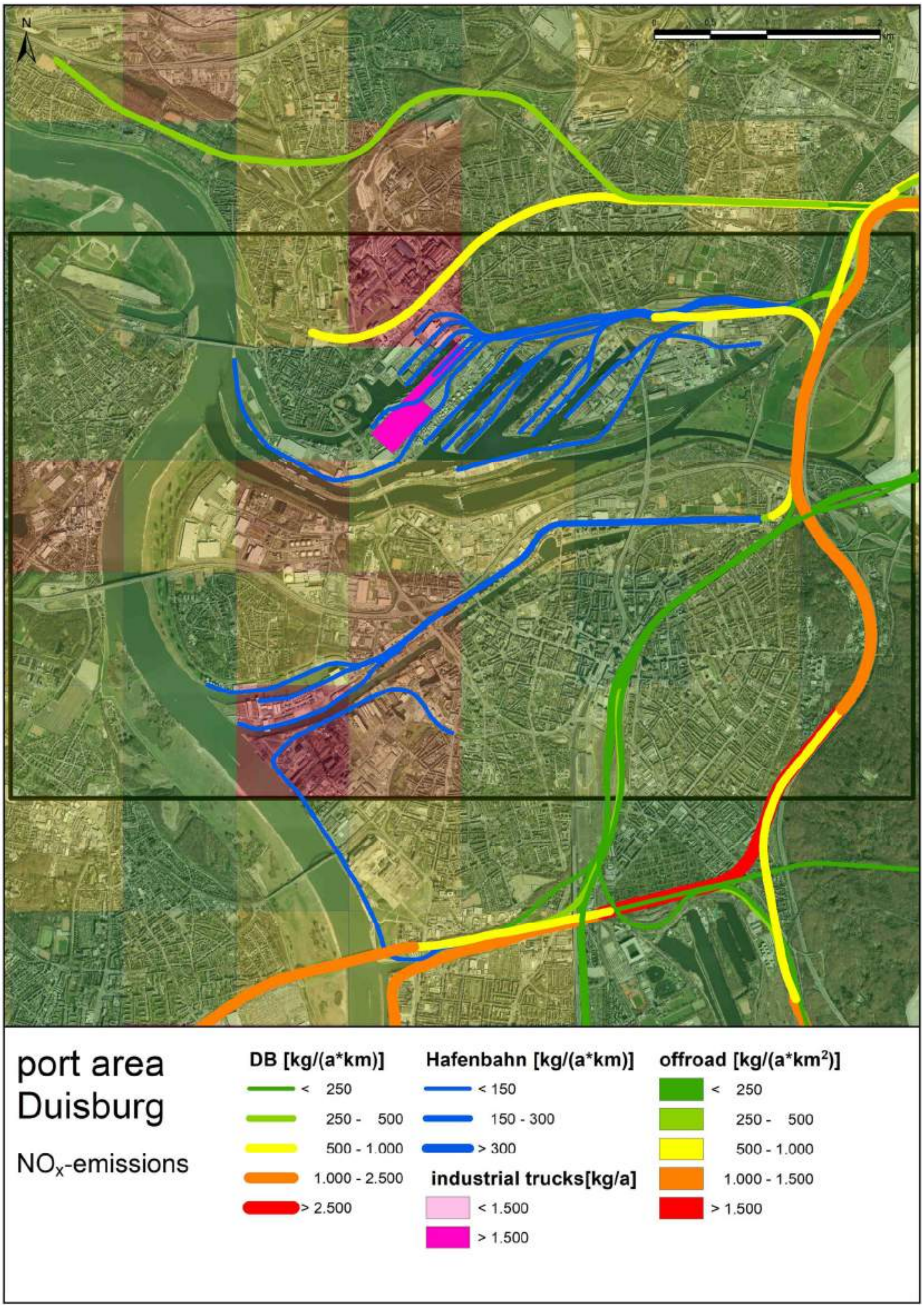

Figure 28: Annual NO_X emissions from train, off-road and air traffic sources in the Duisburg port area, analysis year 2018

Figure 29: Annual NO_X emissions from road traffic in the Duisburg port area, analysis year 2018

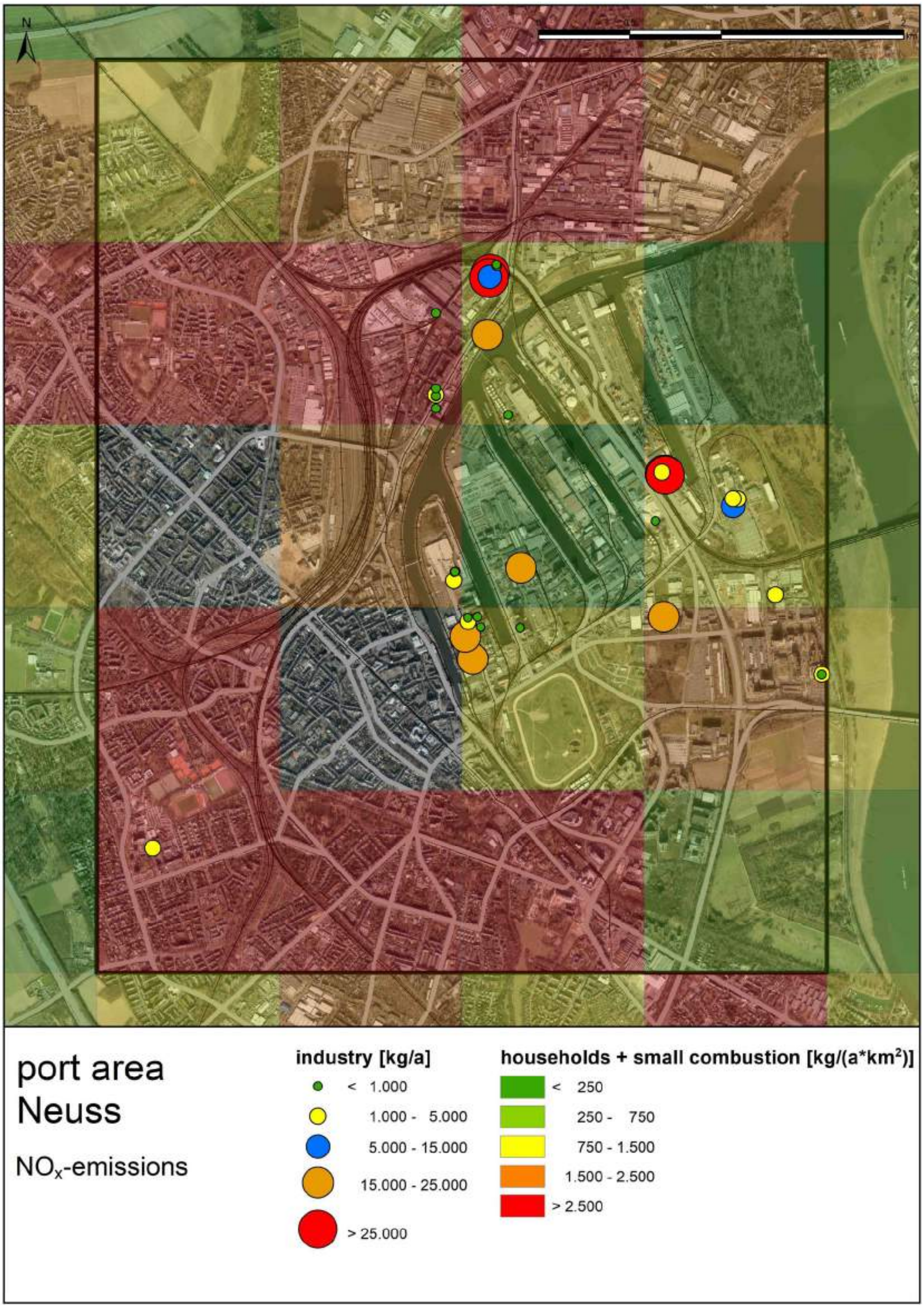

Figure 30: Annual NO_X emissions from industrial sources, small combustion plants and domestic furnaces in the Neuss port area, analysis year 2018

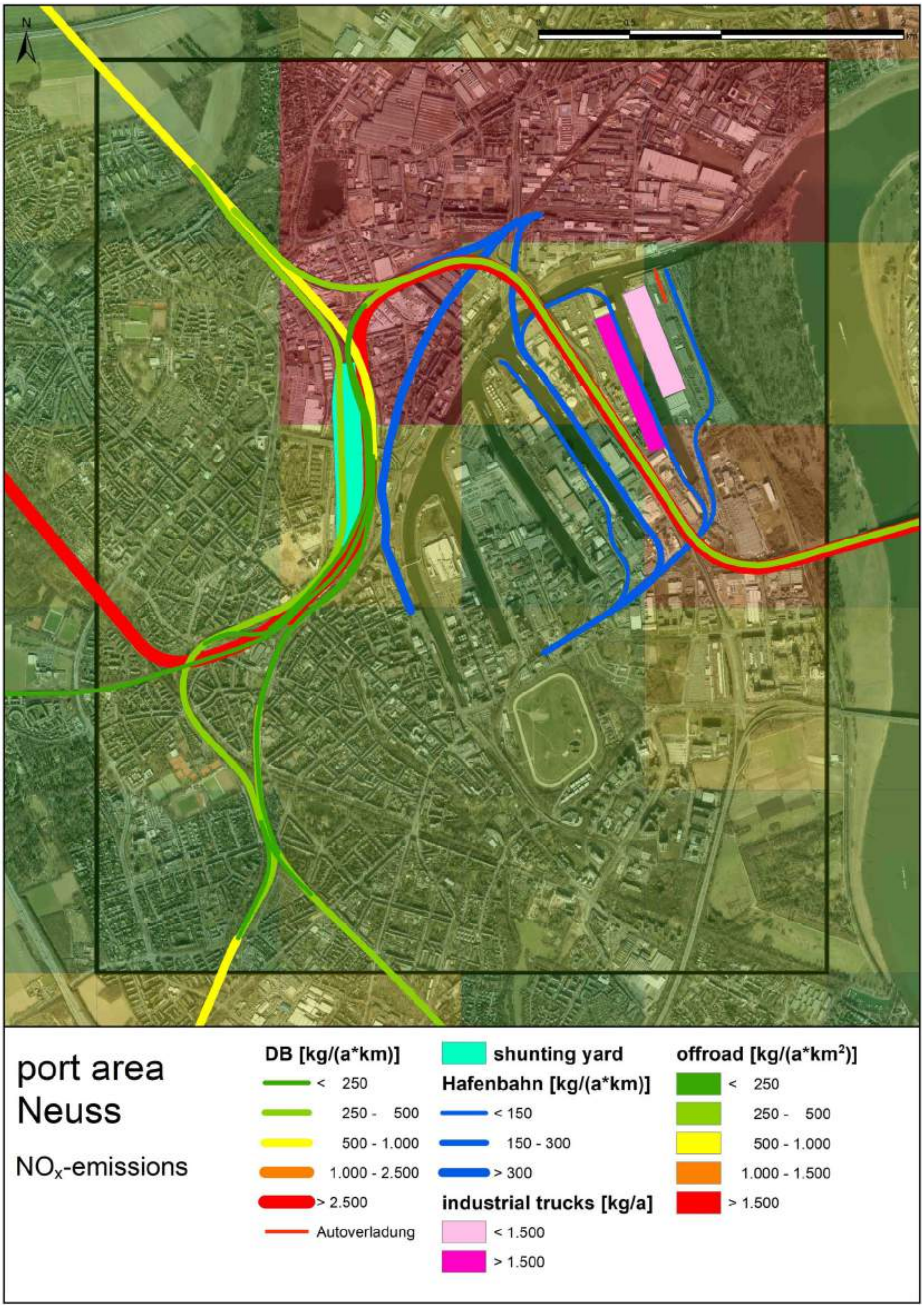

Figure 31: Annual NO_X emissions from train, off-road and air traffic sources in the Neuss port area, analysis year 2018

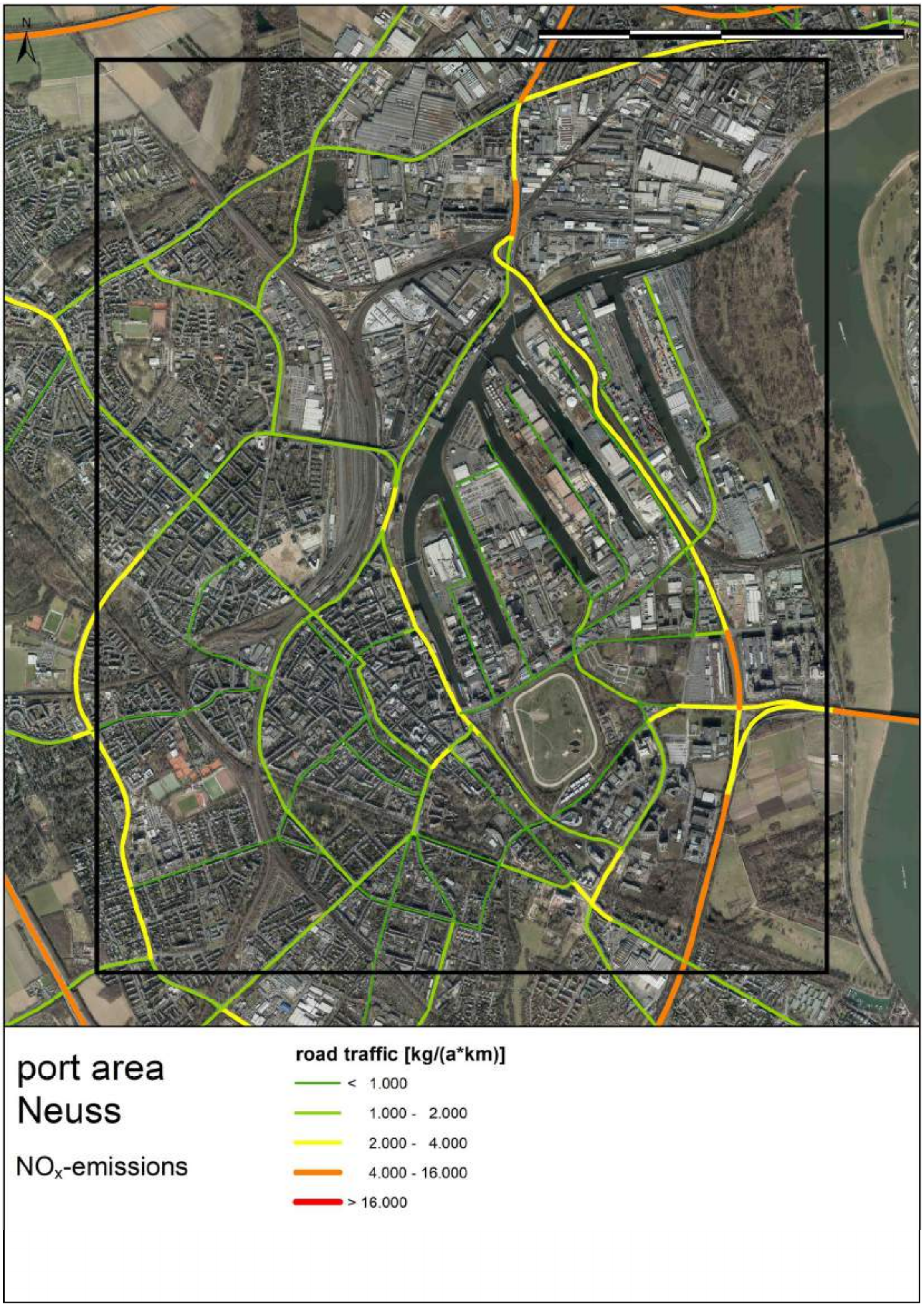

Figure 32: Annual NO_X emissions from road traffic in the Neuss port area, analysis year 2018

Appendix A: Duisburg port railway (number of trips per day)

Number of rail transport trips in the port area (front: number of locomotives, back: number of trips) /LANUV 2019a/

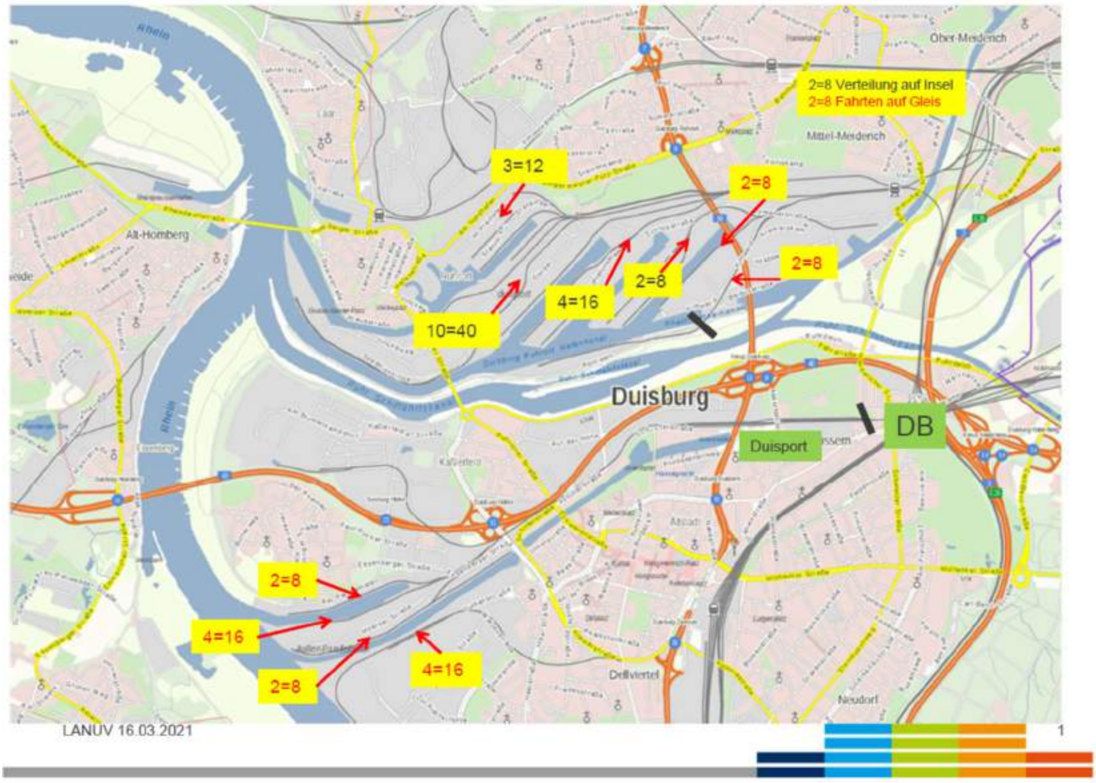

Figure 33: Number of trips of the locomotives of the Duisport port railway according to the port operators.

2=8 means: Two trains are run daily on this line, i.e. the locomotive runs four times per train. I.e. the locomotive brings the empty wagons and then drives back again. After the loading is completed, the locomotive returns to the train and pulls the wagons out of the harbour basin area.

Appendix B: Locomotives in use Port of Duisburg

Table 31: Overview of locomotives in use (locomotive fleet) (LANUV 2019b)

(yellow: own, green: hired)

Baureihe	NVR-Nummer	Motor-Nr
V100 (BR 202)	98 80 3202 778-7	CAT 3512: 3ZW00396
203	92 80 1203 004-7	MTU 12B4000R10, S/N: 526100833
G1206D	9280 1275 021-4	CAT 3512: F2X00134
G1206	9280 1275 107-1	CAT 3512: 3ZW00372
G1206	9280 1275 631-0	CAT 3512: 3ZW00925
B&V Leipzig		
G761C (7)	98 80 0262 005-8	MTU: 6V331 S/N: 5501034
DT502 (29)	98 80 0271 102-2	MTU: 6V396 S/N: 5550792
DT502 (30)	9880 0271 103-0	MTU: 6V396TC13, S/N: 5550795
G1206D	9280 1275 015-6	CAT 3512: 3ZW01051
G1206D/NL	9280 1275 635-1	CAT 3512: 3ZW00866
V90	9880 3295 014-5	8M282AK B: 5470035
V90	9880 3295 025-1	8M282AK B: 5470011
V90	9880 3295 027-7	8M282AK B: 5470109
V90	9880 3295 061-6	8M282AK B: 5470044

Anhang C: Neuss port railway (number of trips per day)

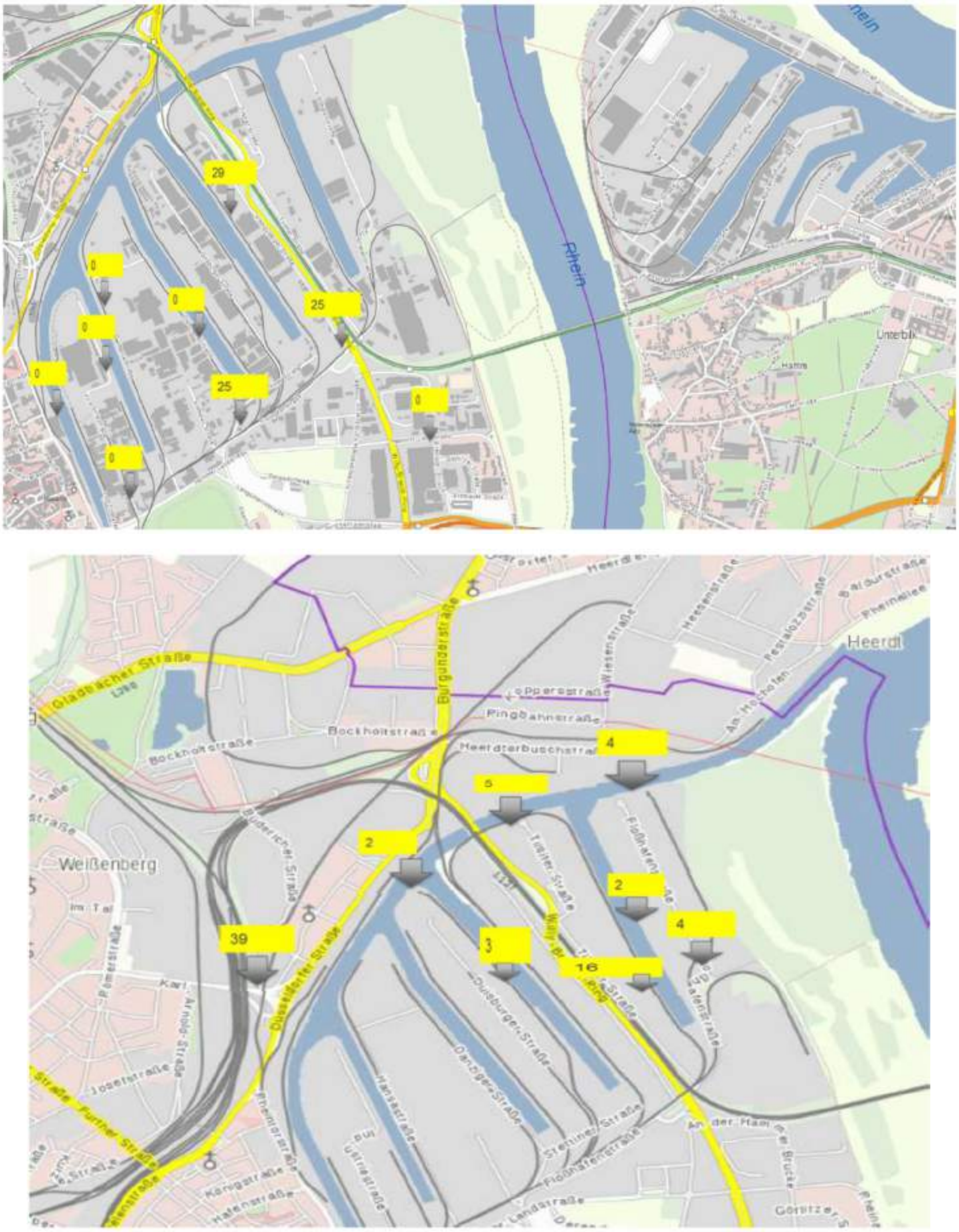

Figure 34: Number of trips of the locomotives of the Rheincargo port railway in the port of Neuss according to the port operators.

2=8 means: Two trains are run daily on this line, i.e. the locomotive runs four times per train. I.e. the locomotive brings the empty wagons and then drives back again. After the loading is completed, the locomotive returns to the train and pulls the wagons out of the harbour basin area.

Figure 35: Number of trips of the locomotives of the Rheincargo port railway in the port of Düsseldorf according to the port operators.

Appendix D: Locomotives used Neuss port area

Table 32: Locomotive data from technical sales documents

Name	Abgasnorm	Verbrauch	Wert	Einheit
12V4000R43L	UIC IIIA Rail (Kodex 624V); EU Nonroad St IIIA Comp (97/68/EG);	Spezifischer Kraftstoffverbrauch (be) - 100% BL (+5%; EN 590; 42,8MJ/kg)	210	g/kWh
		Kraftstoffverbrauch bei unterer Leerlaufdrehzahl	6,3	kg/h
		Schmierölverbrauch nach 100h Laufzeit (B = stündlicher Kraftstoffverbrauch)	0,3	% von B
		Schmierölverbrauch nach 100h Laufzeit, max. (B = stündlicher Kraftstoffverbrauch)	1	% von B

Abgasemissionen	Wert	Einheit
Vorschrift: UIC IIIA (Stand 2009) Stickoxide (NOx)	6,0	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Kohlenmonoxyd (CO)	3,5	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Unverbrannte Kohlenwasserstoffe (HC)	0,5	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Partikel	0,2	g/kWh

Name	Abgasnorm	Verbrauch	Wert	Einheit
8V4000R43L	UIC IIIA Rail (Kodex 624V); EU Nonroad St IIIA Comp (97/68/EG);	Spezifischer Kraftstoffverbrauch (be) - 100% BL (+5%; EN 590; 42,8MJ/kg)	206	g/kWh
		Kraftstoffverbrauch bei unterer Leerlaufdrehzahl	4,2	kg/h
		Schmierölverbrauch nach 100h Laufzeit (B = stündlicher Kraftstoffverbrauch)	0,3	% von B
		Schmierölverbrauch nach 100h Laufzeit, max. (B = stündlicher Kraftstoffverbrauch)	1	% von B

Abgasemissionen	Wert	Einheit
Vorschrift: UIC IIIA (Stand 2009) Stickoxide (NOx)	6,0	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Kohlenmonoxyd (CO)	3,5	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Unverbrannte Kohlenwasserstoffe (HC)	0,5	g/kWh
Vorschrift: UIC IIIA (Stand 2009) Partikel	0,2	g/kWh

14. CLINSH Partner

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